
Photo: Gregg M. Taylor

Air crew radiation exposure—An overview

BY SUSAN BAILEY

Regulators, airlines, and flight crews are paying more attention to cosmic radiation. But what is the risk, and how can it be managed?

It is an established fact that an increase in altitude means an increase in radiation. A move from a coastal state to the Rocky mountains, for example, is known to increase an individual's background radiation dose. On an airplane, that level of radiation is higher still.

In 1990, the International Commission on Radiation Protection (ICRP) identified airline flight crews as a group occupationally exposed to radiation, reversing a policy that kept any natural source of radiation free from regulation. Radiation doses received by pilots and flight attendants are often greater than those received by traditional radiation workers in the heavily regulated nuclear industry, but, until recently, little attention was paid to occupationally exposed air crew. Now, sophisticated equipment is allowing researchers to undertake studies of such radiation exposures, and in some regions of the world new legislation is in place to monitor air crew exposures. It will be up to the government, airlines, and air crew to determine what these exposures will mean for the future of air travel.

Flying is now a common mode of transportation, but recent changes in air travel may mean an increase in dose to exposed individuals. High-powered, high-altitude aircraft such as the Concorde commonly fly at 55 000 feet, and future aircraft might fly even higher. Galactic cosmic radiation exposure approximately doubles with every 6000 feet of increased altitude. While cosmic radiation poses little or no risk to the "pleasure" traveler, business travelers who log as many hours as air crew themselves could be labeled occupationally exposed. Additionally, radiopharmaceuticals being transported as cargo can increase the radiation dose to crew members.

The Federal Aviation Administration (FAA) first acknowledged radiation risks in 1990, with the publication of Advisory Circular 120-52, "Radiation Exposure of Air Carrier Crewmembers." According to that report, the average dose rate in the contiguous United States from cosmic and terrestrial radiation is 0.06 microsieverts (μSv)/hr. At an altitude of 35 000 feet, which is common for domestic air travel, the dose rate from galactic cosmic radiation alone is 6 μSv/hr.

Advisory Circular 120-61, dated May 19, 1994, contains the FAA's official recommendations to U.S. airlines regarding in-flight radiation. It simply states, "Air carrier crewmembers are occupationally exposed to low doses of ionizing radiation from cosmic radiation and from air shipments of radioactive materials." The two-page document recommends that airlines educate crewmembers on the types and amounts of radiation received during air travel, with comparisons to other sources of exposure; variables that have an effect on the amount of radiation exposure (for example, altitude, latitude, and solar flares); guidelines regarding exposure to ionizing radiation; health risks to crewmembers from cosmic radiation; special considerations needed to limit the exposure of a fetus to cosmic radiation; how crewmembers can manage their exposure; and radioactive material shipments.

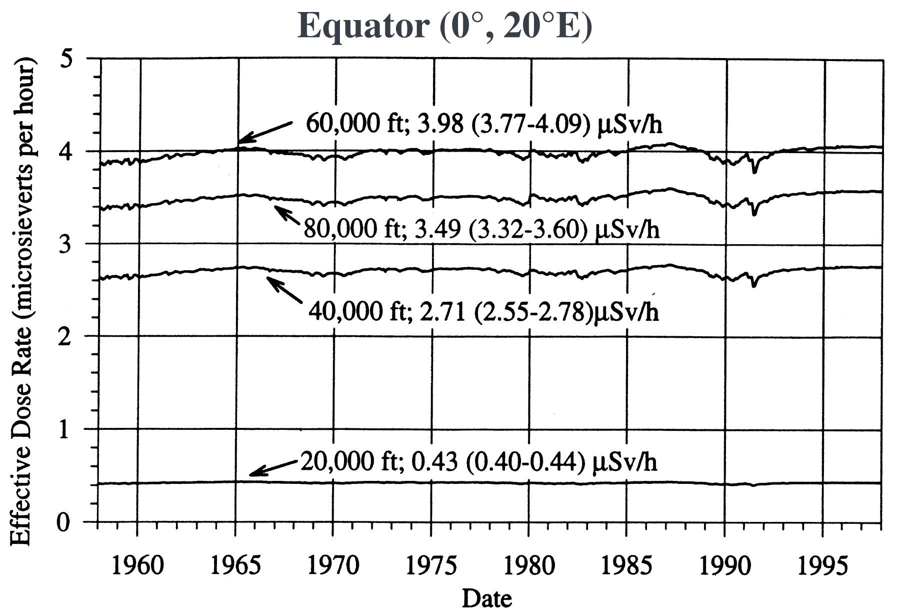


Fig. 1. Galactic radiation levels (monthly means) at various altitudes, at the equator and at a high latitude, January 1958–December 1997. Forty-year mean (minimum-maximum) effective dose rates are also shown. The effect of the 11-year solar cycle on cosmic radiation levels is apparent at high latitude.

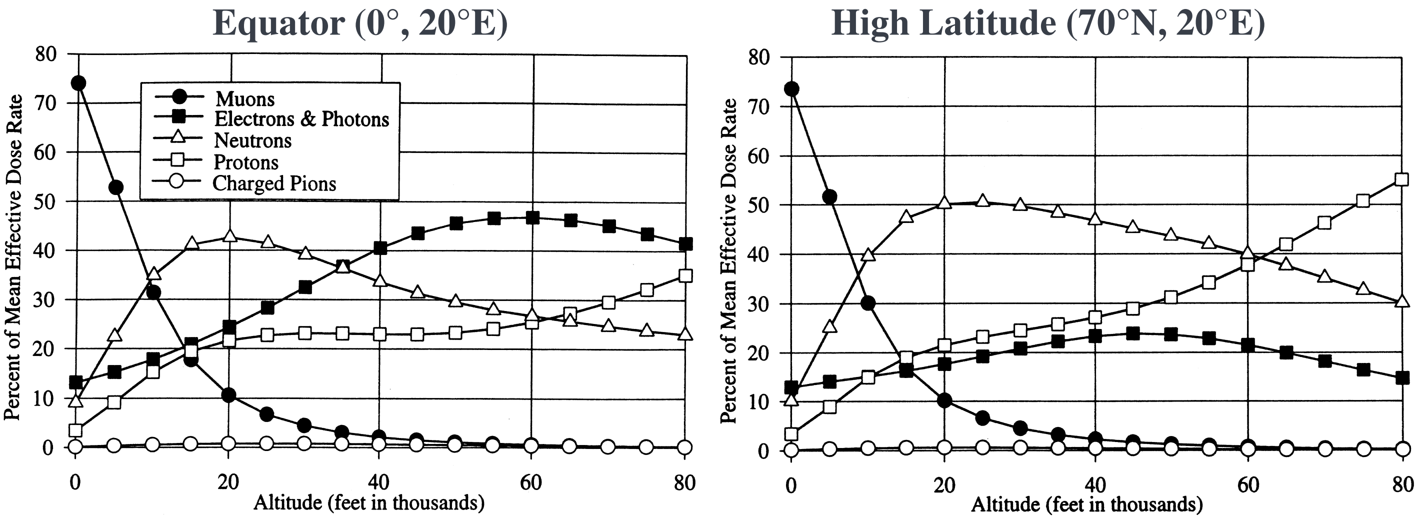
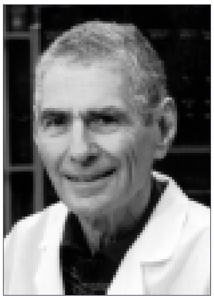


Fig. 2. Percent contributions to the mean effective dose rate of galactic radiation by its components as related to altitude, at the equator and at a high latitude, January 1958–December 1997 (Source: W. Friedberg, et al., ibid. Reproduced with permission from Nuclear Technology Publishing.)

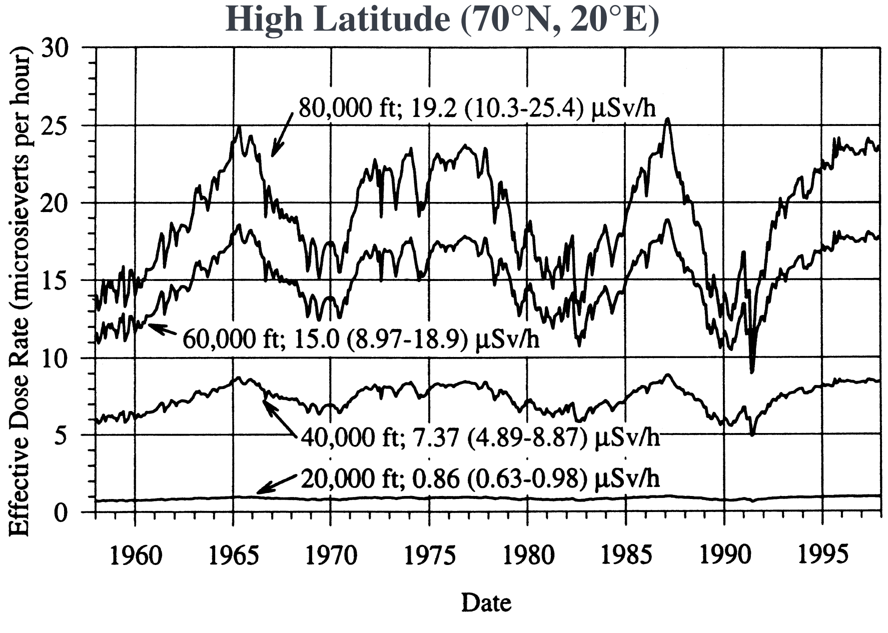
What exactly is it?

Ionizing radiation particles (mostly protons and alpha particles) enter Earth's atmosphere, where they collide with nitrogen, oxygen, and other atoms, breaking apart their nuclei. Both the charged particles entering the solar system and the secondary radiation they produce in the atmosphere are referred to collectively as galactic cosmic radiation. Each disrupted nucleus can itself yield multiple ionizing particles, which can interact with other nuclei and produce still more particles, until, after several interactions, they have lost the energy to cause disruptions. The sun is also a considerable source of radiation; solar radiation and galactic cosmic radiation are commonly referred to jointly as cosmic radiation.



Friedberg

Wallace Friedberg, team leader of the radiobiology research group at the FAA's Civil Aeromedical Institute (CAMI) in Oklahoma City, Okla., explained in a 1998 meeting paper that the effect of galactic cosmic radiation generally declines with decreasing altitude. Radiation levels are also lower near the equator than toward the north and south poles, Friedberg explained, because the Earth's magnetic field deflects incoming galactic cosmic radiation particles (particularly those with low energy). The effect of the Earth's magnetic field is greatest at the geomagnetic equator, which is located near the geographic equator. From data gathered during January 1958–December 1997, Friedberg was able to estimate that an airplane at an altitude of 20 000 feet at 70° North latitude (near the Arctic circle) would receive galactic cosmic radiation a factor of 2.0 higher than at the same altitude at the equator (see Fig. 1). He presented the paper, "Guidelines and Technical Information Provided by the U.S. Federal Aviation Administration to Promote Radiation Safety for Air Carrier Crewmembers," at the International Conference on Cosmic Radiation and Aircrew Exposure, Implementation of European Requirements in Civil Aviation, on July 1–3, 1998, in Dublin, Ireland.



(Source: W. Friedberg, et al. Reproduced from *Cosmic Radiation and Aircrew Exposure,* pp. 323–328, with permission from Nuclear Technology Publishing, P.O. Box 7, Ashford, Kent TN23 1YW, England.)

At every latitude, the altitude at which the dose rate is highest is different. The initial interaction of galactic cosmic radiation with the Earth's atmosphere can be so intense that a unique phenomenon is observed at high altitudes above the equator: The intensity of the radiation is lower at 80 000 feet than at 60 000 feet, where particle interactions reach their peak.

Friedberg was able to identify the particles responsible for the galactic cosmic radiation dose to an aircraft cruising at typical altitudes of 20 000–40 000 feet. At that altitude, and over his 40-year study period, 88–97 percent of the effective dose rate was from neutrons (33–52 percent), protons (21–28 percent), and electrons and photons (17–41 percent) (see Fig. 2). Muons contribute 2–11 percent, and charged pions less than 1 percent.

Cosmic radiation levels are never constant. Researchers have been taking measurements for nearly 50 years, and have identified an 11-year cycle of galactic cosmic radiation intensity, which is influenced by the sun's activity. Solar particle events (SPEs), also known as solar flares, can occur at any time, but occur more frequently during a few years of that cycle, known as solar maximum. When the basic dipole component of the sun's continually varying magnetic field reverses direction, solar minimum is reached, and SPEs are infrequent and less powerful.

The solar wind (a plasma of solar radiation—mostly protons and electrons—ejected from the sun) carries a convoluted magnetic field throughout the solar system. This wind

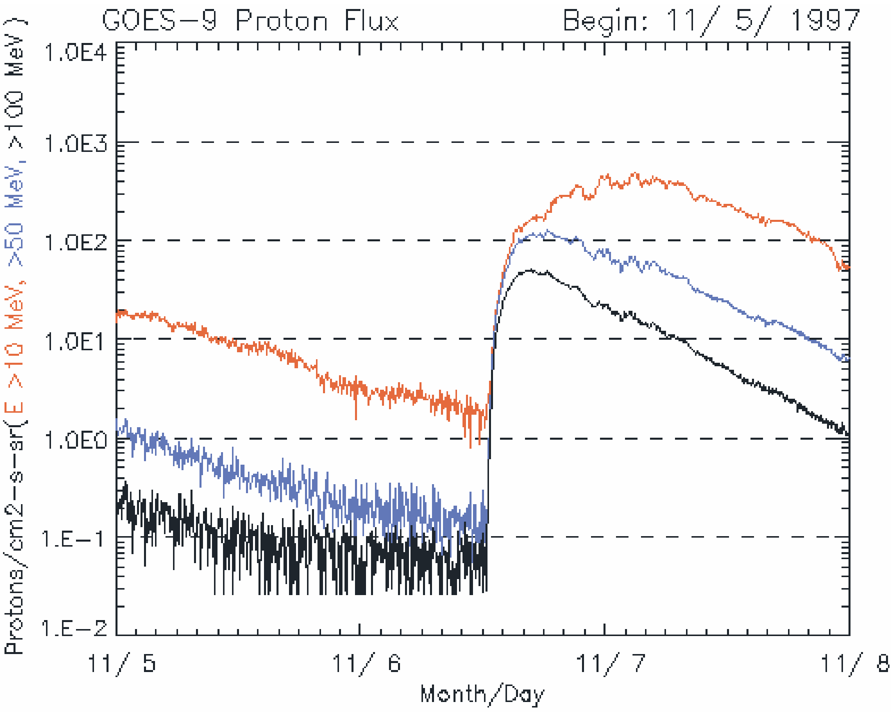


Fig. 3. Data acquired during the solar particle event of November 4–7, 1997, by the GEOS-9 satellite, showing the intensity of solar protons in three energy ranges (>10 MeV, >50 MeV, and >100 MeV) (Source: NOAA)

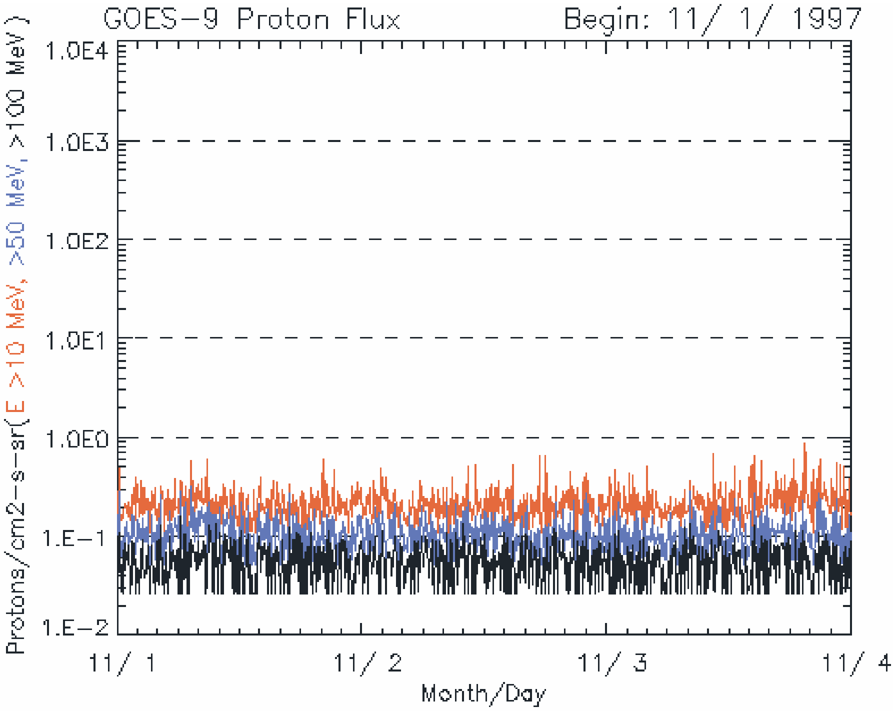


Fig. 4. Data acquired under normal solar conditions, by the GEOS-9 satellite, showing the intensity of solar protons in three energy ranges (>10 MeV, >50 MeV, and >100 MeV) (Source: NOAA)

contains more irregularities at solar maximum, which makes the magnetic field change and become unusually tortuous and strong. Since the ionized particles making up galactic radiation are electrically charged, they can be affected by the highly ionized particles in the solar wind. "Irregularities in the magnetic fields carried by the solar winds scatter the low-energy galactic particles that would otherwise enter the Earth's atmosphere," Friedberg told *Nuclear News*. Because of this, galactic cosmic radiation is at a minimum during solar maximum, but during solar minimum, more of that radiation can reach the Earth. The most recent solar minimum occurred in early 1997, and solar maximum is expected to begin ahead of schedule in May 2000, according to Friedberg.

SPEs are usually too low in energy to contribute to radiation levels at the altitudes commonly reached by a standard airplane. Occasionally, however, during solar maximum, the numbers and energies of these solar radiation particles increase enough to affect the cosmic radiation dose to air travelers. SPEs are short-lived: They commonly rise to a peak radiation level and then drop to near normal levels within two–three hours. Figure 3 illustrates solar proton levels, as measured by the National Oceanic and Atmospheric Administration's Space Environment Center, on November 7, 1997, when a measurable solar flare occurred (Fig. 4, by contrast, shows typical solar proton levels).

The strongest SPE ever recorded occurred on February 23, 1956. At the time, no measurements of cosmic radiation at high altitudes could be made, and researchers have used models to estimate the dose that a person flying at a high altitude during the SPE would have received. Paul Goldhagen, a physicist with the Department of Energy's Environmental Measurements Laboratory, in New York, N.Y., explained that researchers have performed extrapolations to determine that an SPE with the strength of the 1956 event could mean a dose equivalent of more than 10 millisieverts (mSv)/h to the passengers and crew of a high-latitude supersonic flight.

SPEs could have more of an effect on future high-flying jets. A hypothetical supersonic transport (SST) would contain an onboard radiation monitor, as the Concorde does now, that could warn pilots of the onset of an SPE if air traffic controllers were not able to do so. If this monitor indicated an SPE was occurring, the plane could evade the radiation by lowering its altitude from 65 000 feet to approximately 45 000 feet, or by moving to a lower latitude. "That's fine when you have one plane flying," said Goldhagen. "If you've got a hundred SSTs in the year 2050, it's suddenly more dangerous for them all to try to go down to a lower altitude at once than it is to sit there and accept the radiation." By that time, he theorizes, it may be possible to predict when an SPE is likely.

An SPE could also affect the SST of the future by interfering with the avionics onboard. A single event upset, or SEU, could occur if ionizing radiation damages a computer chip, and could put the aircraft in jeopardy. It is possible, Goldhagen theorizes, that if no steps are taken to prevent radiation from upsetting avionics, the biggest health threat to passengers and crewmembers from radiation may be from resulting malfunctions in the aircraft.

How large a dose?

Friedberg has developed a computer program that can estimate the galactic radiation dose received on a flight between any two airports in the world. The latest version of that program, CARI-5E, is available on the Web at <www.cami.jccbi.gov/AAM-600/610/600radio.html>. The program takes into account the location of an airplane from takeoff to touchdown, including the altitudes reached during the flight and the time spent at each altitude, as well as latitude and longitude changes. Using the date of flight entered by the software user, CARI-5E adjusts its dose estimation to reflect the 11-year so-

Table I. Effective Doses of Galactic Cosmic Radiation Received on Air Carrier Flights

	Single nonstop one-way flight				
Origin – Destination	**Highest Altitude, feet in thousands**	**Air time, hours**	**Block hours**	**Effective dose, microsieverts[a]**	**Millisieverts per 100 block hours[b]**
Seattle WA – Portland OR	21	0.4	0.6	0.14 (0.11 – 0.15)	0.02
Houston TX – Austin TX	20	0.5	0.6	0.14 (0.12 – 0.15)	0.02
Miami FL – Tampa FL	24	0.6	0.9	0.34 (0.28 – 0.36)	0.04
St. Louis MO – Tulsa OK	35	0.9	1.1	1.57 (1.20 – 1.74)	0.14
San Juan PR – Miami FL	35	2.2	2.5	4.84 (4.16 – 5.18)	0.19
Tampa FL – St. Louis MO	31	2.0	2.2	4.31 (3.35 – 4.74)	0.20
New Orleans LA – San Antonio TX	39	1.2	1.4	3.11 (2.54 – 3.31)	0.22
Los Angeles CA – Honolulu HI	35	5.2	5.6	12.9 (11.5 – 13.3)	0.23
Denver CO – Minneapolis MN	33	1.2	1.5	3.54 (2.56 – 4.05)	0.24
New York NY – San Juan PR	37	3.0	3.5	9.20 (7.52 – 10.1)	0.26
Honolulu HI – Los Angeles CA	40	5.1	5.6	15.2 (13.4 – 15.8)	0.27
Chicago IL – New York NY	37	1.6	2.0	6.09 (4.33 – 7.10)	0.30
Los Angeles CA – Tokyo JP	40	11.7	12.0	38.0 (31.8 – 40.4)	0.32
Tokyo JP – Los Angeles CA	37	8.8	9.2	30.0 (24.6 – 32.2)	0.33
Washington DC – Los Angeles CA	35	4.7	5.0	17.2 (13.2 – 19.1)	0.34
New York NY – Chicago IL	39	1.8	2.3	8.42 (5.93 – 9.85)	0.37
Minneapolis MN – New York NY	37	1.8	2.1	7.91 (5.54 – 9.26)	0.38
London GB – Dallas/Ft. Worth TX	39	9.7	10.1	38.8 (27.6 – 45.1)	0.38
Lisbon ES – New York NY	39	6.5	6.9	27.3 (20.5 – 31.1)	0.40
Dallas/Ft. Worth TX – London GB	37	8.5	8.8	35.3 (24.8 – 41.4)	0.40
Seattle WA – Anchorage AK	35	3.4	3.7	15.1 (10.4 – 17.8)	0.41
Chicago IL – San Francisco CA	39	3.8	4.1	17.7 (13.2 – 19.8)	0.43
Seattle WA – Washington DC	37	4.1	4.4	20.4 (14.3 – 23.8)	0.46
London GB – New York NY	37	6.8	7.3	34.0 (23.8 – 40.0)	0.47
San Francisco CA – Chicago IL	41	3.8	4.1	19.5 (14.2 – 22.1)	0.48
New York NY – Seattle WA	39	4.9	5.3	25.6 (17.7 – 30.1)	0.48
New York NY – Tokyo JP	43	13.0	13.4	67.1 (48.3 – 77.7)	0.50
London GB – Los Angeles CA	39	10.5	11.0	55.2 (38.5 – 64.9)	0.50
Chicago IL – London GB	37	7.3	7.7	38.7 (26.6 – 45.8)	0.50
Tokyo JP – New York NY	41	12.2	12.6	63.5 (44.3 – 74.8)	0.50
London GB – Chicago IL	39	7.8	8.3	43.3 (29.6 – 51.6)	0.52
Athens GR – New York NY	41	9.4	9.7	58.2 (42.3 – 67.0)	0.60

[a] Mean (minimum–maximum) effective dose, January 1958–December 1997.
[b] Based on the mean effective dose for the one-way flight.

(Source: W. Friedberg, et al., ibid. Reproduced with permission from Nuclear Technology Publishing.)

NASA ER-2 taking off. Radiation sensors for the AIR measurements were carried in the nose, the fuselage behind the cockpit, and the front third of both wing pods. (Source: DOE Environmental Measurements Laboratory, presented at the 1998 NCRP Annual Meeting, "Cosmic Radiation Exposure of Airline Crews, Passengers, and Astronauts")

lar cycle. The program can estimate dose on any flight from January 1958 to the present, providing a useful tool for epidemiologists trying to assess possible health effects caused by long-term cosmic radiation exposures to air crew.

Table I illustrates typical mean, minimum, and maximum dose rates received on flights over the last 40 years. According to Friedberg, a flight attendant working 700 block hours annually (measured from the time the aircraft leaves the blocks before takeoff to when it reaches the blocks after landing) flying between Athens, Greece, and New York City would receive an annual occupational exposure of 4.2 mSv. Friedberg explained in his paper that based on the data in the table, the average annual radiation dose to crewmembers from occupational and nonoccupational sources can vary. For some, it can be close to the amount received by the general population, and for others it can be twice that amount.

At the request of the National Aeronautics and Space Administration (NASA), the Na-

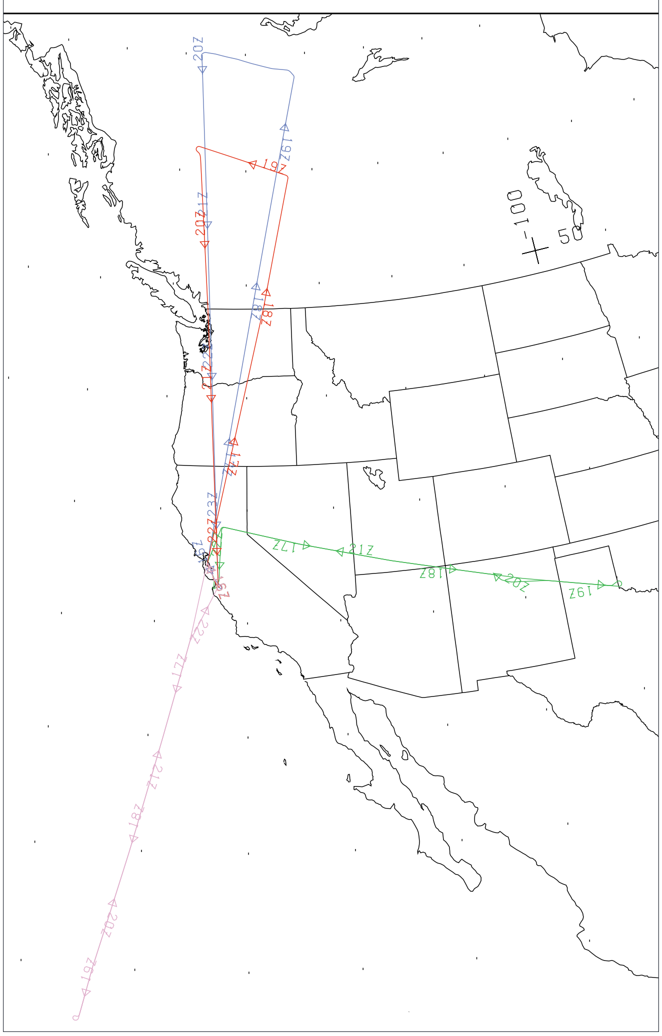


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Fig. 5. Flight paths of the AIR measurement ER-2 flights (Source: DOE Environmental Measurements Laboratory, presented at the 1998 NCRP Annual Meeting, ibid.)

tional Commission on Radiation Protection studied radiation exposure and high-altitude flight, and in July 1995 published Commentary 12, which recommended that “average absorbed dose rates and their uncertainty in the altitude range of 30 000 to 80 000 feet require greater specification, and additional measurements utilizing currently flying high-altitude aircraft should be made with adequate instrumentation” to eliminate that uncertainty.

Since then, the NASA High Speed Research Project Office, working out of the agency’s Langley Research Center under the direction of John W. Wilson, has attempted to characterize radiation conditions at high-altitude flight. Assisting in the mission were the DOE’s EML, NASA’s Johnson Space Center, the Canadian Defense Research Establishment and Royal Military College, German Aerospace Research Establishment, U.K. National Radiological Protection Board, Boeing Company, and several researchers from domestic and foreign universities.

Galactic cosmic radiation measurements were made using a converted military spy plane, the ER-2, which can reach altitudes of 75 000 feet. Behind the mission, known as the Atmospheric Ionizing Radiation (AIR) project, was the need for accurate characterization of radiation levels at the high altitudes that would be reached by a hypothetical SST.

The ER-2 plane was used on a series of five missions flown from NASA’s Ames Research Center at Moffett Field, Calif., in June 1997 (during the last solar minimum), when galactic cosmic radiation exposures could be expected to be at their highest (see Fig. 5). Fourteen different instruments were contained within the plane, including a multisphere neutron spectrometer, ionization chamber, and scintillation counters from EML, two spherical tissue-equivalent proportional counters, and two particle telescopes. Data from the flights were collected to allow further refining of the AIR model of the galactic cosmic radiation environment, and to permit precise dose estimates for high altitudes.

Regulators have their say

It has been acknowledged that the radiation doses crewmembers receive constitute occupational exposure, but should this exposure be limited? Governments worldwide are now deciding how to address the risk of radiation to air crew.

In the United States, the FAA has published documents discussing air crew radiation exposure, and has issued recommendations to airlines on educating air crew about the risks—but it has not issued dose limits. U.S. airlines have not voluntarily adopted training or dose monitoring programs similar to those in the nuclear power industry. Friedberg told *Nuclear News* that his research group at CAMI "will continue providing information and making recommendations. We don't have any regulations, however, at the moment. That is something that may or may not happen in the future. . . . If there is enough of a reaction in the aviation community [the FAA] might feel compelled to do it."

As shown in Table II, air crew typically receive more radiation exposure than radiation workers at a nuclear facility. Most groups of "terrestrial" radiation workers include a number of people whose occupational exposure is near zero, which lowers the average effective dose. All air crew, however, are exposed to unavoidable radiation for the duration of a flight, so their average effective dose is relatively high.

According to Robert Barish, of New York, N.Y., a medical physicist and certified health physicist who has worked in radiation oncology, and who speaks and writes about cosmic radiation, considering that crewmembers are occupationally exposed to radiation, "they are a legitimate, regulated radiation cohort that should be told about the risks. Unfortunately, the airlines have never told them." In Europe, by contrast, airlines must begin informing air crew of their radiation doses in May 2000. The European Union's radiation protection policy is contained in the EU Directive on the protection of workers and members of the public against the hazards of ionizing radiation (96/29/Euratom), which is binding on all member states and is revised every 10–12 years.

The Directive generally matches ICRP recommendations, and requires that the dose received by any crewmembers who may receive more than 1 mSv per year should be assessed. In addition, airlines will be required to organize the schedules of crewmembers with the objective of reducing the doses of highly exposed air crew, educate the crew about health risks, and give special protections to women who have declared pregnancy. Flight attendants at British Airways, for example, are "grounded" immediately after declaring pregnancy, and are given other tasks until they take maternity leave, according to Michael Bagshaw, head of Medical Services at the airline. Individuals who may receive more than 6 mSv per year may be subject to more stringent measures after May 2000, such as warning signs or individual dosimetry.

TABLE II. ANNUAL EXPOSURE, QUALITY OF EXPOSURE, AND RISK COEFFICIENT UNCERTAINTY OF U.S. RADIATION WORKERS

Group	Exposure (mSv)	Quality Low LET, %	Distribution High LET, %	Risk uncertainty factor
Terrestrial occupations	2.2	93	7	2.1-3.8
Aircraft:				
subsonic	5-9	32	68	3.4-10.8
supersonic	8-17	32	68	3.4-10.8
hypersonic	14-21	28	72*	3.4-11.6
Low earth orbit:				
low inclination	17	62	38	2.8-7.6
high inclination	144	34	66*	3.3-10.9
Deep space	500	14	86**	3.7-13.3

*Significant exposures to HZE (highly charged, energetic) ions.
**Exposure dominated by HZE ions (Source: NASA, presented at the 1998 NCRP Annual Meeting)

What do crewmembers think?

The International Federation of Air Line Pilots Associations (IFALPA) is trying to make its concern about radiation exposures known. IFALPA represents approximately 100 000 pilots from pilot associations in about 90 different countries, including the United States. The organization's Human Performance Committee held a meeting in October 1998, and produced a policy proposal similar to the EU Directive that states, among other things, that long-range airplanes normally operated above 8000 m (26 000 ft) should carry equipment to measure and indicate continuously the dose rate of total cosmic radiation being received, the cumulative dose on each flight, and the presence of any solar flares. All crewmembers, the policy said, should be allowed to adjust their flying schedules so that they do not exceed an annual threshold limit of 6 mSv/year.

The policy was approved by IFALPA member associations at a conference held in April 1999. Herbert Meyer, senior technical officer at IFALPA headquarters in the United Kingdom, admitted, "this issue has been the subject of extensive debate within IFALPA and the Human Performance Committee in particular, and as is the case in the entire scientific community, no conclusive findings have been reached." The policy approved in April was revised by the IFALPA Human Performance Committee at an October 1999 meeting. The revised policy, not yet approved by the IFALPA member associations, reads as follows:

"IFALPA policy recognises 20 mSv/yr as the cosmic radiation limit for airline flight crews as established by the National Council of Radiation Protection and Euratom. It is further recognized that airline flight crews should be categorised as occupationally exposed radiation workers, likely to receive more than 1 mSv/yr. As cosmic radiation imposes a potential health risk to airline flight crews, it is highly recommended that national authorities make provisions for exposure assessment verification. . . . Crew members should be made aware through extensive educational programs that high altitude flying exposes them to significantly higher ionising radiation levels, with carcinogenic potential, than the general population and the scope of radiation protection legislation. . . . Flight crew members should be warned that radiation exposure above 1 mSv during the course of the entire pregnancy may cause an increased risk to the fetus. Operators should have provisions in place to adjust flight duties (low altitude flights that minimise exposure/ground duties) so that this limit is not exceeded after declaration of pregnancy by the flight crew member."

Emily Carter, national health coordinator for the Association of Professional Flight Attendants (APFA), says that most flight attendants on U.S. carriers have an "underlying knowledge" that cosmic radiation could pose a threat, but that they currently don't feel there is anything they can do about it. This may change, however. U.S. flight attendants have the opportunity to interact with their international counterparts, and as European flight attendants begin to monitor their exposures in May 2000, those from the United States might begin to wonder why they don't get dose estimates as well, said Carter. "The flight attendants on U.S. carriers are going to be very angry that they're exposed to this, but they're not going to want to cut down their lifestyles," she predicted. "They're just going to get angrier." Although the mitigation or monitoring of radiation doses has not been an issue in contract negotiations between

Artist's conception of a manned Mars mission, by Pat Rawlings, of SAIC, for NASA. The radiation environment 70 000 ft above the Earth is very similar to that on the surface of Mars. (Source: NASA)

Far out!

Although the ER-2 plane did not leave the Earth's atmosphere, its data is still useful to the NASA researchers pondering a mission to Mars. According to Robert Singleterry, a research scientist at NASA's Langley Research Center (LRC) who participated in the high-speed research project, the radiation environment 70 000 ft above the Earth is very similar to that on the surface of Mars.

The concept of aerial density, measured in g/cm^2, allows NASA researchers to make comparisons between different atmospheres, even if they are composed of different elements, Singleterry explained. Aerial density is the sum of the mass of all the matter, in this case molecules of atmospheric gas, above any given cm^2 area. The measurement is significant because it identifies the amount of mass between an incoming cosmic radiation particle and a planet or other object, according to Singleterry. "[The number of] molecules the cosmic ray would see as it comes in to penetrate the atmosphere and either hit the Martian surface or hit the airplane would be the same," he said.

Astronauts face a greater likelihood of suffering health effects from occupational exposure to cosmic radiation than do air crew (see Table II). They are exposed to more radiation, and a large percentage of the radiation is high-LET (linear energy transfer) particles. If astronauts were inadequately shielded at the time of a large solar particle event, life-threatening injuries could occur, as John Wilson, senior research scientist at LRC, explained in "Overview of Radiation Environments and Human Exposures," a paper he presented at the 1998 NCRP Annual Meeting. NASA's researchers cannot guess when a large SPE might happen; they must therefore design equipment that can help astronauts withstand the largest possible solar radiation exposure.

Extensive experimentation must still be conducted, because, as Wilson told *Nuclear News,* "space exposures are quite different than anything that is experienced either at high altitude or on the surface [of Earth]." Even on missions to the Moon, spacecraft receive some protection from the Earth's magnetic field, but there will be no such protection in deep space.

NASA has moved away from the traditional radiation protection practice of setting a radiation dose limit and regulating to keep exposures below that limit, Wilson said. Instead, the focus is starting to shift to controlling the excess fatal cancers astronauts could develop later in life as a result of a deep space mission. Currently, NASA has the goal of limiting the probability of an astronaut's developing fatal cancer to less than 3 percent. "We're willing to limit the risk to 3 percent," said Wilson, "but we don't know how to limit it, and we don't know what kind of shielding materials are going to be the best way to help out." If NASA is to achieve its official goal of amassing enough technical information by 2004 to make an educated decision on whether to attempt a manned mission to Mars in 2014, those problems will have to be solved soon, according to Wilson.

Singleterry, a former DOE contractor, explained the difficulties of attempting to shield astronauts. While terrestrial radiation workers can limit their time near a radiation source, distance themselves from the source, and erect thick shielding, an astronaut cannot. Because any additional weight added to a spacecraft increases its cost, NASA engineers are forced to be creative. Aluminum, which is commonly used in spacecraft, does not shield people from damage as well as water or liquid hydrogen can, for example. "It's really hard to build stuff with liquid hydrogen," said Singleterry, "but it's a great fuel." If astronauts were surrounded by their liquid hydrogen fuel, they would be better protected. The effectiveness of that shield, however, would decrease as the mission wore on. NASA has considered providing small, heavily shielded "storm shelters" onboard to which the astronauts could retreat during an SPE.

NASA must also worry about protecting equipment from single event upsets. NASA's existing space shuttle experiences approximately 400 computer upsets during a two-week mission, according to Singleterry. For that reason, the shuttle has five redundant computers. The computers "vote" on critical decisions; any computer that has been damaged and produces faulty information is overruled by the others. NASA is able to test the ability of some equipment to withstand tough radiation environments by irradiating it with an electron beam. "For deep space, we're going to have to start radiating some of these parts in front of heavy, high-energy ion beams," said Singleterry.

NASA researchers currently use Brookhaven National Laboratory's Alternating Gradient Synchrotron (AGS) to test spacesuit and spacecraft materials in high radiation environments similar to those in space. Biologists use the same beam to irradiate cell cultures, mice, and rats, according to Singleterry. They are trying to learn what damage high-LET radiation can do to individual cells, and how a biological system reacts to that damage. NASA is building a permanent structure at BNL to perform a large volume of similar tests in support of a possible future manned mission to Mars. The Booster Application Facility, due to open in 2002, will be an adjunct to BNL's AGS.—*SB* flight attendant unions and airlines, Carter expects that within six years it will become a negotiating point.

It is not easy for concerned flight attendants to estimate their own exposures. “Dosimetry badges were pretty much discouraged because it’s going to give them a false sense of security,” said Carter. Traditional dosimetry badges cannot accurately measure the types of radiation found at high altitudes. However, “the company would never let you [wear dosimetry badges],” Carter said, “because of the perception that the passengers would have.” Flight attendants could use a computer program such as the FAA’s CARI-5E to make estimates, but the most accurate measure of the dose received on any flight would come from an onboard radiation monitor.

Although some U.S. airlines permit flight attendants to continue flying until the 26th week of pregnancy, according to Carter, APFA distributes materials to its members from the FAA’s Civil Aeromedical Institute which suggest caution during pregnancy. Flight attendant unions such as the APFA are “the only people that are going to [educate the flight attendants about cosmic radiation] because the airlines aren’t going to do it. . . . They’re not made to, so why should they?” said Carter. The airlines have not chosen to educate their employees, in part, Carter believes, because they do not want the traveling public to become alarmed. Although cosmic radiation has not received much attention yet, “the minute we get help with it, it’s going to become a major concern. And the help is going to come from the European group.”

Radiation protection

But is the regulation really necessary? After all, crewmembers are at no risk of receiving an extremely high dose such as could result during an accident at a nuclear facility. The primary health effect is radiation-induced cancer. But if that cancer risk is practically undetectable, given the normal risk everyone faces, is there any cause for concern?

Researchers who study cosmic radiation, with its increased amounts of high-LET (linear energy transfer), particles originating in deep space, have not been able to identify conclusively the health effects that may result from the exposure an average crewmember receives. Most of the data that radiation protection specialists have at their disposal is from research on low-LET radiation. Friedberg, whose group at CAMI provides the research behind the FAA’s recommendations, explained that “our group has made risk estimates, but I do it with great caution in that I tell people that they shouldn’t take it overly seriously. We don’t know enough about the cosmic radiation environment.”

The most recent cancer risk estimates published by the FAA, in 1992, appeared in “Radiation Exposure of Air Carrier Crewmembers II.” Friedberg warned that while the general discussion in the document is still correct, the dose figures and risk estimates within would be different if he recalculated using current, improved data. The document states, for example, that “if a crewmember worked 700 block hours a year for 30 years, exclusively on flights with average en route altitudes of 33–40 thousand feet between the contiguous United States and Europe, then the estimated risk of radiation-induced fatal cancer would be between 1 in 250 and 1 in 120.” One in five U.S. adults in the general population will likely die of cancer, the document continues, so “the likelihood of developing fatal cancer because of occupational exposure to galactic radiation is a small addition to the general population risk.” An increased risk of childhood cancers and birth defects, particularly mental retardation, can result from extended radiation exposures to pregnant crewmembers, according to the document.

The 1992 document acknowledges the annual occupational radiation exposure limit of 20 mSv suggested by the ICRP, and states that estimated doses to crewmembers are “considerably lower” than the limit. For pregnant flight crewmembers, however, “once a pregnancy is known . . . the dose equivalent to the unborn child from occupational exposure should not be more than 0.5 mSv in any month.” For radiation protection purposes, the dose equivalent to a fetus is considered to be the same as that received by the mother.

Monitoring all flight crew members is no small task: In the United States alone, there are more than 160 000 people who make a living on airplanes. Beginning in May 2000, however, airlines in Europe will have to do just that. “I think the European Union is on track to realize its deadline of May 2000 for having in place a way to determine the doses for air crew and I think that’s an appropriate thing to do,” said the DOE’s Goldhagen.

Airborne ALARA

Radiation protection specialists employed at nuclear power plants continually try to reduce the dose their workers receive, and the industry has benefited from successfully lowering exposures. The principle of ALARA, keeping dose “as low as reasonably achievable,” is encouraged by regulators. But would the same principle work onboard airplanes? Goldhagen said, “Merely paying attention to ALARA constantly makes the allowable limits tend to creep downward, which is a good thing on average. But the airplane case is different, because you can’t put up more shielding or spend less time near the source [as you can in a nuclear power plant], which is what they had in mind.”

Richard Killick, a director of the consulting firm Sage Safety and a former director of safety and quality for Scottish Nuclear before its privatization, believes that poor public relations and secrecy in the early days of the nuclear industry created a climate of distrust. Expensive lawsuits and claims for compensation from alleged radiation-induced illnesses have increased. In a paper presented at the Aviation Health Institute meeting in June 1999, in London, “ALARA—‘As Low As Reasonably Achievable’: Applying Lessons from the Nuclear Industry to Aviation,” Killick advised airlines to take preventive actions. “A very cost-effective lesson that the airline industry can learn from the nuclear industry,” he said, “is to put in place an industry-wide procedure for the practical and quantifiable application of the ALARA principle.” Airlines should, Killick said, be prepared to offer comparisons between cosmic radiation and radiation from other natural and manmade sources. Also, airlines should establish a legal procedure to calculate the appropriate reimbursement for different exposure levels before compensation claims are made, Killick suggested.

Killick discussed dose-reduction measures that could effectively lower the dose exposure of air travelers. Flying at lower altitudes, or a different latitude, would certainly result in a lower dose, but is impractical. Cutting back on the flying times for air crew would require more trained staff, at a huge expense. While heavy lead shields could not be installed in airplanes, the structure of the plane, the bulk of luggage, and the bodies of other passengers all offer shielding, which means that radiation levels are different in different parts of the plane. The occupants of window seats, for example, receive more dose than those in the aisle. Killick suggested the unique idea of moving the air crew, pilots included, to areas of the plane with lower radiation levels.

In an April 1999 article published in the U.K. NRPB’s Radiological Protection Bulletin (which was reproduced in the Health Physics Society Newsletter of June 1999), “Equalising the Window Seaters: Practical Control of Cosmic Ray Doses During Air Travel,” Gerald M. Kendall of the NRPB outlined a recent design study by a consortium of aircraft manufacturers that involved the installation of a “modified mechanical conveyor” in an airplane cabin. In this concept, passenger seats would move slowly, taking approximately 45 minutes to travel through the cabin, spending equal time in “window seats” and the center of the plane. The arrangement, Kendall suggests, has some secondary benefits. Passengers could disembark in an orderly fashion, as their seat passes the door of the aircraft. Drinks and food could be distributed self-service, as passengers pass a cafeteria area. The result would be a cut in staffing needs. The U.S. Marines, Kendall reported, are testing the idea in modified troop carrier aircraft.

Of course, concerned individuals could lower their exposures by simply not boarding an aircraft, but flying is a practical means of travel, and cosmic radiation poses no harm to the ordinary traveler. But what if a pregnant woman, for example, wanted to avoid the risk of flying during an SPE? Robert Barish has begun a telephone service, which, for the price of $3, the traveler can call from the airport. If radiation levels are higher than normal, she will be advised that she may wish to delay her flight for a few hours. “If you’re pregnant, particularly at an early stage, and you can avoid an exposure by waiting a few hours until the radiation has subsided, I think that’s in conformity with ALARA,” Barish said.