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REVIEW

Cosmic radiation in commercial aviation

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Summary
This paper reviews the current knowledge of cosmic radiation and its applicability to commercial aviation. Galactic cosmic radiation emanates from outside the solar system, while occasionally a disturbance in the suns' atmosphere leads to a surge in radiation particles. Protection is provided by the suns' magnetic field, the earths' magnetic field, and the earths' atmosphere. Dose rates are dependent on the altitude, the geomagnetic latitude and the solar cycle. For occupational exposure to ionising radiation, which includes aircrew, the International Commission on Radiological Protection recommends maximum mean body effective dose limits of 20 mSv/yr (averaged over 5 years, with a maximum in any 1 year of 50 mSv). Radiation doses can be measured during flight or may be calculated using a computer-modelling program such as CARI, EPCARD, SIEVERT or PCAIRE. Mean ambient equivalent dose rates are consistently reported in the region of 4–5 μSv/h for long-haul pilots and 1–3 μSv/h for short-haul, giving an annual mean effective exposure of the order 2–3 mSv for long-haul and 1–2 mSv for short-haul pilots. Epidemiological studies of flight crew have not shown conclusive evidence for any increase in cancer mortality or cancer incidence directly attributable to ionising radiation exposure. Whilst there is no level of radiation exposure below which effects do not occur, current evidence indicates that the probability of airline crew or passengers suffering adverse health effects as a result of exposure to cosmic radiation is very low.

Introduction

Aircraft occupants are exposed to elevated levels of cosmic radiation of galactic and solar origin. The intensity of the different particles making up atmospheric cosmic radiation, their energy distribution, and their potential biological effects vary with altitude, geomagnetic latitude, and the point of time in the sun's magnetic activity cycle.

The sun has a varying magnetic field, which reverses direction approximately every 11 years. Near the reversal, at 'solar minimum', there are few sunspots and the sun's magnetic field extending throughout the solar system is relatively weak. At solar maximum there are many sunspots and other manifestations of magnetic turbulence.

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When the solar magnetic field is stronger, less galactic cosmic radiation reaches the earth. Thus solar maximum causes a radiation minimum and, conversely, solar minimum is at the time of radiation maximum. At commercial jet aircraft operating altitudes, the ratio for galactic cosmic radiation at solar minimum to that at solar maximum is about 1.2–2 and increases with altitude.

The earth's magnetic field has a larger effect than the sun's magnetic field on cosmic radiation approaching the atmosphere. The protective effect is greatest at the equator and least at the magnetic poles. At jet aircraft operating altitudes, galactic cosmic radiation is 2.5–5 times more intense in Polar regions than near the equator.[1]

The earth's surface is shielded from cosmic radiation by the atmosphere, the ambient radiation decreasing with altitude by approximately 15% for each increase of around 2000 ft (dependent on latitude).

As well as providing shielding from galactic cosmic radiation, the atmosphere contributes different components to the radiation flux as a function of atmospheric depth. The total effective dose rate at 30,000 ft is about 90 times the rate at sea level, with neutrons being the dominant component above 10,000 ft.

Solar flares

About once per year a solar particle event (SPE) occurs causing an observable increase in the intensity of the cosmic radiation field at commercial jet aircraft operating altitudes. Since 1956, no event has presented any risk of attaining an annual dose of 1 mSv (the recommended public exposure limit).[2–4]

Disruption of long distance radio communications and activity of the Aurorae Borealis and Australis are not an indication of increased ionising radiation levels at flight altitudes.

Protection against effects of cosmic radiation

The International Commission on Radiological Protection (ICRP) recommended in 1991 that exposure of flight crew members to cosmic radiation in jet aircraft should be considered part of occupational exposure to ionising radiation.[5]

In 1994, the USA Federal Aviation Administration (FAA) recommended that air carrier aircrews should be informed about their radiation exposure and associated health risks, and that they be assisted in making informed decisions with regard to their work environment.[6]

In Europe, the Council of the European Union (EU) adopted a directive laying down safety standards for the protection of the health of workers and the general public against the effects of ionising radiation, and this was applied to aircrew with effect from May 2000.[7] For aircrew likely to receive exposures in excess of 1 mSv per annum, the employer must:

- assess the exposure of the crew concerned;
- take into account the assessed exposure when organising working schedules with a view to reducing the doses of highly exposed aircrew;
- inform the workers concerned of the health risks their work involves;
- apply special protection for female aircrew during declared pregnancy. This limits the exposure to the foetus to 1 mSv for the duration of the pregnancy and indicates that the dose should be as low as reasonably achievable.

Both the FAA and the EU apply the ICRP limits for occupational exposure of a 5-year average effective dose of 20 mSv/yr, with no more than 50 mSv in a single year.

The recommended exposure limits are summarised in the Table 1.

Cosmic radiation doses

The Concorde supersonic transport aircraft, in service between 1976 and 2003, had ionising radiation monitoring equipment permanently installed and much data were derived.[8–16] A large number of studies have been published giving effective dose rates for sub-sonic flights, validating the available computer modelling programs (such as CARI, EPCARD, SIEVERT and PCAIRE).

Mean ambient equivalent dose rates have been calculated and measured in the region of:

Concorde:	12–15 μSv/h
Long-haul:	4–6 μSv/h
Short-haul:	1–3 μSv/h

For European crew members operating to the maximum flight time limitations, annual mean effective exposures are calculated to be:

Long-haul:	2–4 mSv (<1/5 ICRP recommended dose limit)
Short-haul:	1–2 mSv (<1/10 ICRP recommended dose limit).

Table 1 Maximum mean effective dose limits.

	ICRP	EU	FAA
General public	1 mSv yr^{-1}	1 mSv yr^{-1}	1 mSv yr^{-1}
Occupationally exposed	20 mSv yr^{-1}, 5 yr average, but not more than 50 mSv in 1 yr	20 mSv yr^{-1}, 5 yr average, but not more than 50 mSv in 1 yr	20 mSv yr^{-1}, 5 yr average, but not more than 50 mSv in 1 yr
Foetus equivalent dose	1 mSv yr^{-1}	1 mSv for declared term of pregnancy and ALARA	1 mSv maximum, but 0.5 mSv in any month
Control level	N/a	6 mSv	N/a

A number of airlines have changed flight plans to avoid high geomagnetic latitudes during periods of predicted solar flare ground level events, with significant cost and delays to service. Data indicate that these actions were unnecessary in terms of radiation dose protection.

Health risks of cosmic radiation

In considering the health risks, for an accumulated cosmic radiation dose of 5 mSv/yr over a career span of 20 years the likelihood of developing cancer due to the radiation will be 0.4%, and over 30 years 0.6%. In the western population, 23% will die from some type of cancer so the overall risk increases from 23% to 23.4–23.6%. Compared with all the other risks encountered during the working life, this is very low.[17]

The risk of a child inheriting radiation-induced genetic defects after exposure of a parent to ionising radiation is 1 in 2500 following an accumulated dose of 5 mSv over 20 years. This risk is very low against a background incidence in the general population of approximately 1 in 50 for genetic abnormalities.

When compared with the other risks during pregnancy, the risks to the foetus from cosmic radiation are insignificant. The possible effects are cancer and mental retardation and there is a background rate for both these conditions in the normal population. Exposure to cosmic radiation for 80 block hours per month for a period of 4 weeks increases the risk by between 1 in 6000 and 1 in 30,000 depending on the routes flown.[18]

A study of the mortality of commercial pilots employed by British Airways between 1950 and 1997 showed an increase in life expectancy of between 3 and 5 years when compared with the general population, even taking account of the 'healthy worker effect'. Although rare, death from melanoma (which is directly associated with sun exposure) was the only cause of cancer in excess. Cancers such as leukaemia, which may be linked to radiation exposure, were lower than expected within the pilot population.[17]

A population-based case-controlled study from Iceland in 2005 concluded that the association between the cosmic radiation exposure of pilots and the risk of developing eye nuclear cataracts, adjusted for age, smoking status, and sunbathing habits, indicates that cosmic radiation may be a causative factor in nuclear cataracts among commercial airline pilots.[18] However the study fails to address the variability in objective assessment of cataracts and the possibility of observer bias. Nonetheless, it is known that long-term exposure to the high levels of cosmic radiation in space may be associated with the development of eye cataracts in astronauts. This radiation exposure is many orders of magnitude greater than that experienced in commercial air travel.

A report from the German Center of Aerospace in 2006 concluded that the occurrence of cataract surgery amongst their pilot population is smaller than in the normal population, with no cases of pilots having to undergo cataract surgery during their career (other than one case of traumatic cataract).[19] Other European countries report similar findings.

Any association between exposure to cosmic radiation in commercial flying and the development of cataracts would appear to be weak.

Conclusion

Whilst there is no level of ionising radiation exposure below which biological effects do not occur, current evidence indicates that the probability of airline crew members or passengers suffering any abnormality or disease as a result of exposure to cosmic radiation is very low.

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