

# Exposure of Airline Pilots and Cabin Crew to Cosmic Radiation During Flight—What’s the Fuss?

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## Abstract

*The International Commission on Radiological Protection (ICRP) had in 1990 recommended that civilian aircrew be classified as being occupationally exposed to low-dose ionizing radiation, in view of their increased exposure to cosmic rays at altitude. In 2000, the European Union had gone ahead with legislation which requires all European airlines to monitor cosmic radiation levels during flight and to inform aircrew of the possible health risks. However, the evidence for a causal link between cosmic radiation exposure and health risks remains elusive despite recent findings of increased cancer incidence among airline pilots and cabin crew. The inconclusiveness of the evidence notwithstanding, there are compelling reasons for adopting a prudent and precautionary stance.*

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**Key words:** Aircrew, Aviation, Ionizing radiation

## Introduction

The possible health effects of increased exposure of aviators to cosmic rays at altitude have been a source of concern for some time, although such concern has been largely confined to a relatively small circle of experts in aerospace medicine and radiation biology. But the situation is changing rapidly.

Recent media reports<sup>1,2</sup> highlighting the results of a 1999 United Kingdom National Radiological Protection Board Survey revealed that airline pilots received a higher annual average dose of radiation (4.6 mSv a year) than radiation workers (3.6 mSv a year);<sup>3</sup> and results of epidemiological studies which showed increased cancer incidence among civilian aircrew<sup>4-9</sup> have drawn public attention to the problem. Aircrew members and frequent flyers alike are becoming increasingly worried.<sup>10,11</sup>

In the European Union (EU), where the issue has been politicised, the debate has culminated in legislation. Effective from 13 May 2000, all European airlines are required by law to measure radiation levels on flights and to inform aircrew of the possible health risks.<sup>12</sup>

Just what is cosmic radiation, and is it hazardous to health?

## Cosmic Radiation—What is it?

Cosmic rays are invisible, high-energy, charged particles

of extra-terrestrial origin, travelling at nearly the speed of light and constantly bombarding the earth from all directions. The Austrian physicist, Victor Franz Hess, in an experiment involving a hot air balloon ascent, discovered their existence in 1912. For his discovery, he was awarded the Nobel Prize in Physics in 1936.<sup>13</sup>

We now know that there are two main sources of cosmic rays: a relatively small portion is of solar origin—called “solar cosmic radiation”—while the bulk of it comes from deep space—“galactic cosmic radiation”. Current theory suggests that the latter originate from supernovae, the death explosions of massive stars.<sup>14</sup>

Upon striking the earth’s outer atmosphere, these high-energy particles (mainly protons, alpha particles, electrons, positrons and other heavy nuclei) produce secondary showers of lower-energy, mostly unstable, charged particles which in turn, collide with yet other air molecules, creating still more showers that cascade to the ground.

Only a small dose of low-energy, ionizing radiation (comprising a mixture of stable particles such as protons, neutrons and electrons and transient ones such as muons and pions) eventually make it to sea level. Here the particle flux is approximately one per square centimetre per second compared with 100 particles per square centimetre per second at 15 km (or 60,000 feet) above sea level.<sup>15</sup> The

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cosmic particle flux increases with altitude and latitude, and varies with solar activity.

Thus, a person at sea level would receive about 0.5 mSv dose equivalent a year, while someone constantly exposed to 35,000 feet above sea level—the cruising altitude of subsonic commercial aircraft such as Airbus or Boeing 747—would receive about 26 mSv a year. At 60,000 feet above sea level—the cruising altitude of the supersonic Concorde—the cumulative dose increases to as much as 100 mSv a year. In total, the earth's atmospheric layer provides a shielding effect equivalent to 13 feet of concrete.

Additional shielding is provided by the earth's geomagnetic field as charged particles striking the earth at right angles to the earth's magnetic lines (as is the case around the equator) tend to be deflected towards the poles. Hence, the exposure tends to increase as one moves away from the equator. The exposure at the same altitude over the poles is roughly twice that over the equator. This means that flights over polar routes (e.g., New York to Tokyo or Chicago to London) are exposed to a lot more radiation than those confined to the mid-latitudes.

Periods of intense solar activity, which follow an approximate 11-year cycle of rise and decline, disrupt the earth's magnetic fields in such a way that the galactic component decreases during a solar flare event. However, the additional bursts of cosmic radiation coming directly from the sun, increases the overall dose markedly. The solar cosmic ray component measured in an aircraft during a solar flare event can reach as high as 10 mSv an hour!

### **Aircrew Exposures—What's the Risk?**

According to the US Federal Aviation Agency (FAA) estimates, an airline crew member flying 1000 block-hours annually between Washington, D.C. and Los Angeles at 35,000 feet above sea level would receive 5 mSv per year. However, if the route is New York to Athens instead, and the altitude is 41,000 feet, the exposure increases to nearly 10 mSv per year.<sup>16</sup>

Cumulative exposures of airline pilots and cabin crew range from 0.2 to 9 mSv a year.<sup>17</sup> The majority would thus fall somewhere between the International Commission on Radiological Protection (ICRP)'s current recommended maximum permissible level for the general public of 1 mSv per year and that for radiation workers of 20 mSv a year.

Extrapolating from data for high-dose radiation, Friedberg et al<sup>18</sup> estimated that the increased risk of dying from cancer because of cosmic radiation received over 20 years of flying would range from 0.1 to 5 in 1000. Considering that the risk of dying from cancer in the US adult population is about 220 in 1000, this excess risk due to exposure to cosmic radiation is very small indeed.<sup>18</sup> Nevertheless, the risk is not zero.

The main concerns to human health are radiation-induced cancer, and in the case of pregnant cabin crew, possible harm to the foetus.

### **Cancer Risk—What's the Evidence?**

It is important to remember that little is known of the radiobiological effects of low-dose ionizing radiation, and much less of low-dose ionizing radiation of the type and quantity which airline pilots and cabin crew are exposed to at altitude. A great deal of what we know is inferred by extrapolating from high doses—e.g., from epidemiological studies of victims of Hiroshima and Nagasaki, Chernobyl, as well as ground-based laboratory studies involving acute exposures to a single radiation type and at relatively high doses and dose rates.<sup>19</sup>

There are therefore significant differences between the exposure conditions of crew members on board aircraft and that of most other groups of workers occupationally exposed to radiation. The greater ranges of radiation types and energy associated with the cosmic radiation received during flight must be taken into account when estimating the risk. We do not know, for instance, what weighting factors should be used when computing the probable exposures for the wide range of cosmogenic particles experienced at different altitudes,<sup>20</sup> and we do not know if the harmful effects of ionizing radiation at these levels behave in a dose-response or a threshold-dependent fashion.<sup>21</sup>

Nevertheless, we do know enough to be concerned. We know, for instance, that a single track of low-energy ionizing radiation, of the level that aircrew are exposed to, can produce a double-stranded break in the DNA of a single cell nucleus,<sup>22</sup> and that radiation mutagenesis principally proceeds via DNA deletions through misrepair and misrecombination at DNA double-stranded breaks.<sup>23</sup> A study of astronauts on a 4-month mission to the Mir space station showed significantly increased frequency of chromosome aberrations post flight, compared with samples obtained prior to flight.<sup>24</sup> A significant increase in chromosomal aberrations has also been found in Concorde pilots compared to controls.<sup>25</sup> The same has been demonstrated in civilian pilots and cabin crew of subsonic aircraft.<sup>26</sup>

Even more worrying is the recent discovery of "radiation-induced genomic instability".<sup>27,28</sup> The latter refers to radiation-induced damage to human chromosomes that may show up only after several generations of cell division, raising the spectre of delayed genetic effects on the gene pool of future generations.<sup>29</sup>

As pointed out earlier, a number of cohort studies have shown an increased cancer incidence among pilots and cabin crew. For example, an excess incidence of breast

cancer has been reported among Finnish<sup>4</sup> and Danish<sup>30</sup> airline cabin crew—standardised incidence ratio (SIR), 1.9; 95% confidence interval (CI), 1.2–2.2; and SIR, 1.6; 95% CI, 0.9–2.7, respectively. A similar cohort study of Canadian pilots<sup>5</sup> has shown significantly increased incidence rates for prostate cancer (SIR, 1.9; 90% CI, 1.38–2.49) and acute leukaemia (SIR, 4.72; 90% CI, 2.05–9.31). Norwegian pilots<sup>8</sup> have also been found to have excess risks for malignant melanoma (SIR, 1.8; 95% CI, 1.1–2.7) and non-melanoma skin cancer (SIR, 2.4; 95% CI, 1.3–4.0). However, the difficulties with all these studies include problems of small cohort, the availability of a valid comparison population, and the influence of relevant confounding variables.<sup>31</sup>

A meta-analysis using both published and unpublished cohort studies of aircrew members between 1986 and 1998 concluded that aircrew members appeared to be at risk for several types of cancer, viz., melanoma, brain, prostate and breast cancers.<sup>32</sup> But this is insufficient to pinpoint cosmic radiation as the culprit; other possible exposures could include ultraviolet (UV) radiation, electromagnetic fields and chemical substances. While the epidemiological evidence is inconclusive, the lack of evidence is no proof that the harmful health effects do not exist either. Hence, the current philosophy of taking a cautionary stance. But how cautious should we be, considering that there are social, economic and ethical implications of intervention, and that the issue can easily be politicised?

Just how “safe” is the present ICRP recommended safety limit of 2 mSv a year for pregnant workers (i.e., over the entire duration of pregnancy)<sup>17</sup> is really anyone’s guess. Until 1990, this figure was 13 mSv (Table I). The ICRP experts, in arriving at the “safe” limit of 2 mSv a year for pregnant workers, simply assumed that the dose to the foetus from ionizing exposure is about half the dose at the surface of the mother’s abdomen, giving an effective “safe” dose of 1 mSv per year for the foetus.<sup>34</sup> The problem is, this assumption may not hold true,<sup>34</sup> and in any case, this “safe” limit can easily be exceeded within a month or two of flying regular routes, e.g., between Athens and New York.<sup>35</sup> Should a pregnant female cabin crew be grounded or at least be told of the risks?<sup>36,37</sup> One could venture further to ask whether should female cabin crew members be

screened for the BRCA1 gene, a mutation gene which carries a very high risk of developing female breast cancer?<sup>38</sup>

Unfortunately, the jury is likely to remain out for a long time. This is because as long as no particular cancer or cancer death can be linked specifically to cosmic radiation exposure (as distinct from other lifestyle, dietary or environmental factors),<sup>39,40</sup> no cause-effect relationship can be demonstrated.<sup>41</sup>

### Precautionary Measures—What’s Prudent?

Reduction by shielding is not a practical solution, while reduction by flying at lower altitudes is feasible but costly. Aircrew flight-time limitation appears to be the only viable option.

Thus, Concorde pilots are presently limited to 500 hours flying time per year as opposed to 1000 hours for crews on conventional aircraft. Moreover, the Concorde is fitted with a special warning device and the pilot is required to descend to a safer altitude whenever the safety limit of 0.5 mSv per hour is reached (e.g., during a solar event). Generally speaking, international routes, by virtue of the longer flying hours spent at significantly higher altitudes and the greater range of latitudes covered, entail greater exposures than domestic routes. Global “bizjet” crew who often fly above 50,000 feet do not have the same duty time limits as airline pilots and hence, may be at the greatest risk of all.

In 1990, the ICRP recommended that exposures to cosmic radiation during flight in jet aircraft should specifically be included as part of the occupational exposure of aircrew.<sup>42</sup> In 1992, the FAA acknowledged that pilots and flight attendants in conventional subsonic aircraft may be receiving more radiation annually than the average radiation worker and recommended that airlines educate their crew members about their radiation risk.<sup>16</sup> However, as this was only advisory, and not mandatory, very few airlines have complied.

In 1999, the FAA produced a programme, available on diskette (CARI-6) and downloadable over the Internet at <http://www.cami.jccbi.gov/AAM-600/610/600Radio.html#CARI6EXE>, which enables airlines and aviators to estimate their own risks of exposure. CARI-6 calculates the amount of cosmic radiation received by an individual on an aircraft flying between any two locations in the world, taking into account changes in altitude and geographic location from take-off to touchdown, and the particular stage of the 11-year solar cycle at the time of flight. The results for sample flight profiles are shown in Table II.<sup>43</sup> This allows airlines to predict anticipated exposures and aircrew to make conscious informed choices.

The EU leads the way with respect to legislation. In 1996, it adopted the ICRP’s recommendation when it laid down

TABLE I: ICRP EXPOSURE LIMITS—COMPARISON OF PREVIOUS (1976) AND CURRENT (1990) STANDARDS

|                     | Previous ICRP<br>(1976) limits <sup>33</sup> | Current ICRP<br>(1990) limits <sup>17</sup> |
|---------------------|----------------------------------------------|---------------------------------------------|
| Occupational worker | 50 mSv/year                                  | 20 mSv/year                                 |
| Pregnant worker     | 13 mSv/year                                  | 2 mSv/year                                  |
| Public              | 5 mSv/year                                   | 1 mSv/year                                  |

TABLE II: DOSE EQUIVALENTS FROM GALACTIC COSMIC RADIATION RECEIVED ON AIRLINE FLIGHTS (SELECTED ROUTES)

| Single Non-stop One-way<br>Flight Origin—Destination | Highest altitude<br>km (feet, '000) | Air time<br>(h) | Block time<br>(h) | Dose<br>(mSv) |
|------------------------------------------------------|-------------------------------------|-----------------|-------------------|---------------|
| Houston—Austin                                       | 6.1 (20)                            | 0.5             | 0.6               | 0.1           |
| St. Louis—Tulsa                                      | 10.7 (35)                           | 0.9             | 1.1               | 2.0           |
| Tampa—St. Louis                                      | 9.4 (31)                            | 2.0             | 2.2               | 5.4           |
| New Orleans—San Antonio                              | 11.9 (39)                           | 1.2             | 1.4               | 4.3           |
| New York—San Juan, PR                                | 11.3 (37)                           | 3.0             | 3.5               | 13.0          |
| Los Angeles—Honolulu                                 | 10.7 (35)                           | 5.2             | 5.6               | 22.0          |
| Chicago—New York                                     | 11.3 (37)                           | 1.6             | 2.0               | 8.5           |
| Honolulu—Los Angeles                                 | 12.2 (40)                           | 5.1             | 5.6               | 25.0          |
| Washington, DC—Los Angeles                           | 10.7 (35)                           | 4.7             | 5.0               | 24.0          |
| Tokyo, Japan—Los Angeles                             | 11.3 (37)                           | 8.8             | 9.2               | 46.0          |
| Los Angeles—Tokyo, Japan                             | 12.2 (40)                           | 11.7            | 12.0              | 62.0          |
| New York—Chicago                                     | 11.9 (39)                           | 1.8             | 2.3               | 12.0          |
| London—Dallas/Ft. Worth                              | 11.9 (39)                           | 9.7             | 10.1              | 53.0          |
| Dallas/Ft. Worth—London                              | 11.3 (37)                           | 8.5             | 8.8               | 49.0          |
| Seattle—Anchorage                                    | 10.7 (35)                           | 3.4             | 3.7               | 21.0          |
| Chicago—San Francisco                                | 11.9 (39)                           | 3.8             | 4.1               | 26.0          |
| Seattle—Washington, DC                               | 11.3 (37)                           | 4.1             | 4.4               | 29.0          |
| New York—Seattle                                     | 11.9 (39)                           | 4.9             | 5.3               | 36.0          |
| San Francisco—Chicago                                | 12.5 (41)                           | 3.8             | 4.1               | 29.0          |
| Tokyo—New York                                       | 12.5 (41)                           | 12.2            | 12.6              | 91.0          |
| London—Los Angeles                                   | 11.9 (39)                           | 10.5            | 11.0              | 80.0          |
| New York—Tokyo, Japan                                | 13.1 (43)                           | 13.0            | 13.4              | 93.0          |
| London—Chicago                                       | 11.9 (39)                           | 7.8             | 8.3               | 62.0          |
| Athens, Greece—New York                              | 12.5 (41)                           | 9.4             | 9.7               | 93.0          |

Source: CARI-6—US Department of Transportation, Federal Aviation Administration

its basic safety standards for ionizing radiation.<sup>44</sup> The latter has since been incorporated into the national laws. From 13 May 2000, it has become mandatory for all airlines in the EU to measure radiation levels on flights in order to assess the exposure of aircrew members, to inform them of health risks and to control the level of radiation to the foetus.<sup>12</sup>

## Conclusion

Airline pilots and cabin crew members (and frequent flyers) are occupationally exposed to higher doses of cosmic radiation compared to the general population. The evidence for its harmful health effects, however, remains inconclusive. Nevertheless, there is a small but extant risk.

Better-designed epidemiological studies and more biologically-founded laboratory models are needed to establish causality and to quantify the risks. In the meantime, in the absence of scientific evidence and industry-wide standards for minimising the risks, it would be prudent for airlines to inform aircrew of the potential health risks—based on the available information<sup>45,46</sup> and in as clear and unbiased a way as possible.

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