NRL
National Radiation Laboratory

# THE EXPOSURE OF NEW ZEALAND AIRCREW TO COSMIC RADIATION

## Introduction

The increase in cosmic radiation dose with increasing altitude is a well-known natural phenomenon. The crew of commercial aircraft spend a high proportion of their working hours at altitudes which are very high by the standards of the earth-bound human race. This situation raises questions. How much cosmic radiation are aircrew subjected to? Is exposure to cosmic radiation a health issue for aircrew? Should airlines be taking measures to restrict exposure to cosmic radiation for their aircrew? Is exposure to cosmic radiation an occupational hazard, subject to control by radiation protection legislation or other safety legislation?

## Cosmic radiation

The basic physics of cosmic radiation and its behaviour in the earth's atmosphere and magnetic field has been extensively investigated and is well understood[1,2,3,4]. Very high energy charged particles (galactic particles) in interstellar space are partly deflected towards the poles when they enter the earth's magnetic field. They undergo a variety of nuclear reactions when they enter the earth's upper atmosphere. Less energetic (but still high energy) charged particles from the sun cannot normally penetrate the earth's magnetic field and atmosphere to reach the altitudes of jet aircraft. However, their absorption in the upper atmosphere influences the passage of primary and secondary particles of galactic origin. The flux of galactic charged particles is constant, but the flux of solar particles is variable, increasing markedly during solar flares. These upper atmosphere events will not be described further here. Rather, their consequences at altitudes of interest for aviation and their health significance will be described.

A variety of nuclear particles and ionising radiations have been detected at all altitudes, but at the altitudes of interest here, 7 to 12 km, there are two components of health significance. These are neutrons and the non-neutron components (mainly muons, but also other charged particles and gamma radiation). Supersonic aircraft, at present only the Concorde, fly at greater altitudes, and are exposed to a greater variety and greater intensity of radiation. This is not relevant in the New Zealand context.

The non-neutron dose rates are reliably known from many measurements. This radiation has high energy and the attenuation between the outside and the interior of an aircraft is predictable. The flux of cosmic ray neutrons has also been the subject of many measurements and is well known[5]. However, its energy spectrum is degraded as altitude reduces, and by absorption in aircraft. In any real situation inside an aircraft, the energy spectrum will be markedly influenced by the construction materials of the aircraft, and its loading of fuel, passengers, and cargo. Consequently, there will usually be considerable uncertainty in the derivation of the effective dose rate to air travellers from cosmic ray neutrons, even if the neutron flux incident on the outside of the aircraft is confidently known.

Both the non-neutron and the neutron components of cosmic radiation increase with increasing altitude; the latter more than the former. At ground level, the neutron component is about 10 percent of the total effective dose rate, but at 12 kilometres altitude it is about 50 percent. The total effective dose rate inside commercial aircraft exceeds that at sea level by a factor of up to 30. (The total effective dose rate from all sources increases with altitude from a minimum at sea level, over the sea. Over land, however, the terrestrial radiation from natural radioactivity in the soil reduces with increasing altitude. The net effect is a reduction to a minimum at about 1 km altitude[6].)

The intensity of cosmic radiation is dependent on latitude. At sea level the total effective dose rate at high latitudes is about 1.1 times that at low latitudes. However, at altitudes of significance for aviation, the high latitude effective dose rate is about twice that at low latitudes.

The emission of particles from the sun varies with time. Although few of these particles are energetic enough to penetrate the earth's magnetic field to aviation altitudes, the ionization they produce in the upper atmosphere (the ionosphere) affects the higher energy galactic particles. At times of maximum solar activity, the cosmic ray effective dose rate can be 10 percent less than its typical value at aviation altitude, with a lesser effect at sea level.

When considering the doses to air travellers, the other principal variable is the shielding provided by the aircraft. The nuclear reactions which produce the secondary cosmic radiation occur throughout the atmosphere and within aircraft. The secondary radiation therefore tends to be isotropic. Underfloor cargo holds as well as overhead lockers and fuel tanks in the wing provide shielding. The shielding provided by the aircraft body depends on the aircraft model, and much of it may be provided by the loading of the aircraft with fuel, passengers, and cargo; the effective dose rate has been observed to increase during a journey as fuel is consumed. Dose rates 30% greater in the cockpit than in the passenger cabin have been measured in commercial air liners. Typically, cockpit dose rates exceed cabin dose rates by about 10 percent[6].

All the above variables have been observed from instrumental measurements. However, the interpretation of these measurements introduces considerable uncertainty to the derivation of effective dose. In particular, the precise neutron energy spectrum is rarely known, and the neutron effective dose in any situation can rarely be stated with any certainty. It is not surprising that there is some spread in the effective dose rate derived from different reported measurements. Bearing in mind these uncertainties, the dose rates shown in the table, derived from recent reports[3,7], can be used as an approximate guide.

### Cosmic radiation dose rates (μSv/h)

| altitude (km)<br>altitude (ft) | 0<br>0 | 7.0<br>23100 | 7.5<br>24750 | 8.0<br>26400 | 8.5<br>28050 | 9.0<br>29700 | 9.5<br>31350 | 10.0<br>33000 | 10.5<br>34650 | 11.0<br>36300 | 11.5<br>37950 | 12.0<br>39600 | 12.5<br>41250 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| latitude | | | | | | | | | | | | | |
| 0-25 | 0.029 | 0.9 | 1.0 | 1.3 | 1.5 | 1.8 | 2.1 | 2.3 | 2.8 | 3.4 | 4.1 | 5.0 | 6.0 |
| 25 - 33 | | 1.0 | 1.2 | 1.5 | 1.7 | 2.1 | 2.5 | 2.8 | 3.4 | 4.1 | 4.9 | 6.0 | 7.2 |
| 33 - 40 | | 1.2 | 1.4 | 1.8 | 2.0 | 2.5 | 2.9 | 3.2 | 4.0 | 4.8 | 5.7 | 7.0 | 8.4 |
| 40 - 45 | 0.032 | 1.4 | 1.6 | 2.0 | 2.3 | 2.8 | 3.3 | 3.7 | 4.5 | 5.4 | 6.5 | 8.0 | 9.6 |
| 45 - 50 | | 1.5 | 1.8 | 2.3 | 2.6 | 3.2 | 3.7 | 4.1 | 5.1 | 6.1 | 7.3 | 9.0 | 10.8 |
| 50 - 60 | | 1.7 | 2.1 | 2.5 | 2.9 | 3.6 | 4.1 | 4.6 | 5.7 | 6.8 | 8.2 | 10.0 | 12.0 |
| 60 - 90 | 0.032 | 1.8 | 2.2 | 2.7 | 3.1 | 3.8 | 4.3 | 4.9 | 6.0 | 7.2 | 8.6 | 10.6 | 12.7 |

## Exposure of New Zealand aircrew

The altitude, latitude, and flight times for any individual aircrew of a New Zealand airline are all variable. It is only possible to estimate some average values for these variables. The estimates below are conservative and can be regarded as upper limits. The stated doses are the occupational exposure to cosmic radiation, in addition to the cosmic radiation received by the rest of the population at sea level.

The routes flown by domestic airlines can be broadly classified as main trunk routes and feeder routes, characterised by the type of aircraft flown. The smaller aircraft on feeder routes are generally required to observe an upper altitude limit of about 7.5 kilometres (25 000 feet). The routes are typically short and aircraft will be at the maximum altitude for only a fraction of each flight. In many cases, they will not reach this altitude as the flights are of short duration. The flying hours of each crew member will be only a fraction of their working hours. An aircrew member with 500 flying hours per year, at an altitude of 7.0 kilometres for 25 percent of the flying time but at altitudes of low cosmic ray intensity at other times would receive less than 0.2 millisieverts (mSv) per year from cosmic radiation.

The main trunk routes are flown by two different aircraft models with typical cruising altitudes of 9.3 km (31 000 feet) and 8.2 km (27 000 feet). Their crews have typical flying hours of 500 to 750 hours per year. On average about 30 percent of the flying time is at these altitudes. In each case, crew members are unlikely to receive more than 0.5 mSv per year from cosmic radiation.

Compared with domestic routes, international air routes are characterised by longer flying hours, significantly higher altitudes, and a much higher proportion of time at the maximum altitude. A much greater range of latitudes is covered. The flying hours of aircrew are a greater proportion of their working hours. New Zealand aircrew fly a number of routes, but from the point of view of exposure to cosmic rays, the highest doses would be received on routes from New Zealand to Europe via North America. Aircrew flying these routes for 1000 hours per year, with 90 percent of the time at the maximum altitude of 12 kilometres, and the time divided equally between low latitudes (0 - 40) and high latitudes (40 - 60) would receive an annual cosmic ray dose exceeding 6.5 mSv. Crew flying 1000 hours per year on shorter routes, in the middle latitudes, with 0.7 of the time at an altitude of 11 kilometres, would receive a cosmic ray dose exceeding 3.5 mSv per year. Most New Zealand international aircrew would be exposed to cosmic radiation between these two doses.

There are approximately 700 aircrew employed on New Zealand domestic main trunk routes, each receiving up to 0.5 mSv per year. Aircrew on airlines flying feeder routes receive a fraction of this dose, but the number is somewhat less. The cosmic ray exposure of aircrew is dominated by the approximately 1500 international aircrew exposed to an annual dose in the range 3 to 7 mSv. No other group of radiation workers in New Zealand compares with this group for occupational exposure.

In spite of this situation, cosmic ray exposure of aircrew is of limited health significance. Unlike most other occupationally exposed groups, there is no risk of an accidental high exposure to any individual. The principle health consequence will be radiation induced cancer. For aircrew who fly for 30 years all on the highest exposure routes, the additional mortality risk of cancer is about 1 in 100. For a different selection of routes, it could be as low as 1 in 10 000. The incidence of cancer of this order is not detectable in the presence of the natural incidence of about 1 in 4.

## The legal situation

Under the Radiation Protection Act 1965, the Radiation Protection Regulations 1982 effectively adopt the 1976 recommendations of the International Commission on Radiological Protection (ICRP)[8]. These recommendations exclude all natural radiation from any control. Cosmic radiation to aircrew is not classed as occupational exposure.

It is expected that a revision of the Act and Regulations will effectively adopt the 1990 recommendations of the ICRP[9]. If so, then exposure of aircrew to cosmic radiation will be considered occupational exposure and subject to the limits specified.

Compliance with the current ICRP recommendations is encouraged, ahead of their formal adoption in legislation.

Under current flying conditions, there is no risk of any aircrew approaching the occupational exposure limit of 20 mSv per year. The issue of legal significance is the subsidiary limit specified by the ICRP for pregnant women. This limit is 2 mSv for the duration of the pregnancy, "once pregnancy has been declared". This last phrase is somewhat vague. Given the uncertainties in estimating doses to aircrew, it would be reasonable for airlines to apply a limit of 2 mSv to pregnant aircrew from the estimated time of conception, if they wished to comply with the ICRP Recommendations.

The ICRP limit for pregnant women is based on several biological effects, primarily the risk of stochastic effects later in the life of the exposed foetus, (principally childhood cancer), and to a much lesser extent on birth defects. Among New Zealand's international aircrew there can be up to 40 pregnant women at any time. In the natural course of events, birth defects would be expected occasionally in a group of this size. Although the probability of radiation induced birth defects at the 2 mSv limit is very small, it would be prudent for airlines to ensure that the ICRP Recommendation is complied with.

## Conclusion

Cosmic radiation is a natural phenomenon to which we are all subjected. However, the greatly elevated dose rates found at the altitudes at which commercial aircraft fly should be deemed occupational exposure for the aircrew, in line with the latest ICRP Recommendations. Under current flying conditions, aircrew are the New Zealand occupational group most highly exposed to occupational radiation. International aircrew are exposed to doses probably 10 times those received by domestic aircrew.

Under current flying conditions no aircrew receive doses approaching the 20 mSv per year limit recommended by the ICRP. However, the recommended limit of 2 mSv for the duration of a pregnancy would be exceeded by most pregnant international aircrew if they worked without restriction for the duration of their pregnancy.

Reduction of cosmic radiation dose rates in aircraft by shielding is not practical. Reduction by flying at lower altitudes is feasible, but would probably not be considered an option by commercial airlines. The only viable option for limiting the cosmic ray doses received by aircrew is to limit their flying hours.

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For further information, contact


National Radiation Laboratory
PO Box 25099
Christchurch

Phone: (03) 366 5059
Fax: (03) 366 1156
Internet: http://www.nrl.moh.govt.nz



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