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Cosmic Ray Abundance at Aircraft Altitudes in the Earth's Atmosphere

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Abstract

Recent investigations of cosmic ray primaries and secondaries at aviation altitudes in the Earth's atmosphere include the study of $Z \geq 2$ particles along the London-New York flight routes on supersonic aircraft. Preliminary charge spectra will be presented for these nuclei and comparisons will be made with the predictions of cosmic ray transport models in the Earth's atmosphere.

1 Introduction:

Recently, there has been a significant upsurge in interest in the study of primary and secondary cosmic radiation at aircraft altitudes. The radiation field produced by cosmic radiation in the Earth's atmosphere is very complex and is significantly different to that found in the nuclear industry or other environments at ground level. Today, most national and international flight routes involve cruising altitudes between 10 and 17 kilometres where the intensity of ionising radiation is significant (Heinrich, 1998). The presence of the three main components at these altitudes, namely, the hadron, the electromagnetic and the muon cascades give rise to a significant level of concern about the hazard to biological tissue when prolonged exposure of aircrew is considered. Other factors of interest are the dependence on geomagnetic latitude and the role of varying solar activity.

Several years ago, the European Commission decided to undertake a comprehensive survey of the situation and a programme of experimental and theoretical investigations was initiated (O'Sullivan and Zhou, 1998). One of the main contributions of the Dublin and Siegen groups was to carry out measurements on linear energy transfer (LET) and charge spectra at supersonic and subsonic flight routes and to compare the results with the predictions of cosmic ray transport codes. The ultimate aim of the European investigations is to provide a comprehensive data set as a basis for measuring radiation dose at aircraft altitudes and formulating policy on acceptable limits of exposure time for aircrew.

2 Data Acquisition and Analysis

Detectors were placed inside the passenger cabin of a Concorde aircraft which travelled between London and New York and were removed after a total of 150 flights, corresponding to a total flying time of 450 hrs and 385 hrs at altitude above 9 km. Figure 1 shows a typical flight profile of altitude and Figure 2 shows the corresponding rigidity cut-off profile along the route. The Concorde flights were performed at an atmospheric depth between 130 and 100 g/cm^2 residual atmosphere at cut-off rigidities between 2 and 2.8 GV. These parameters change continuously during the flight. Stacks of USF-4 CR-39 detectors consisting of 20 sheets each of thickness 0.55 mm, were employed in these investigations. The passive nature of the detectors make them ideal for long exposure on aircraft since they do not require any special exposure conditions and do not interfere with aircraft navigation. Following recovery, the plates were etched for 50 hrs in 6.25NaOH at 60^0C. Details of the measurement techniques and data reduction employed in the LET investigations of short range nuclear recoils produced by neutrons on this route are described in (O'Sullivan *et al.,* 1999).

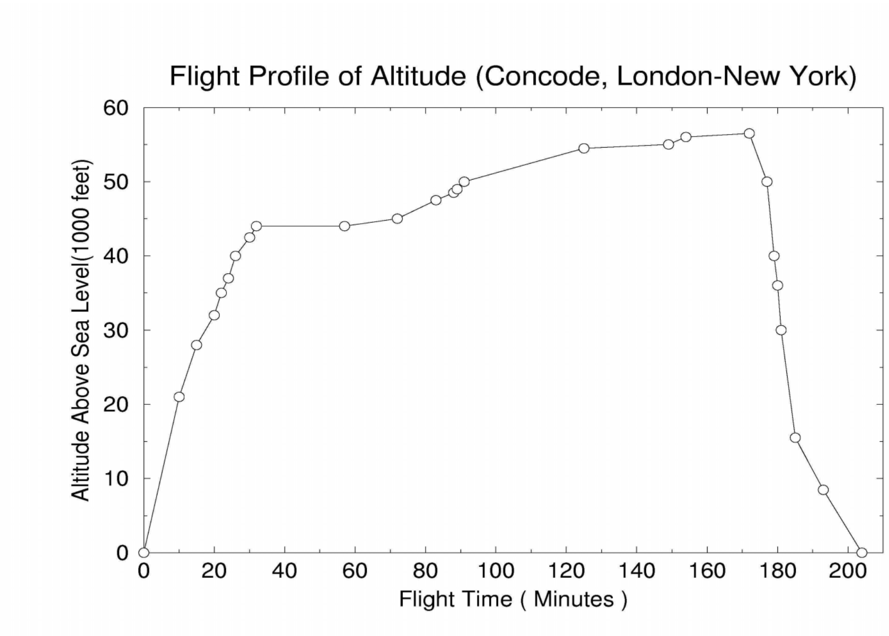

Figure 1: Flight Profile of Altitude (London-New York, supersonic)

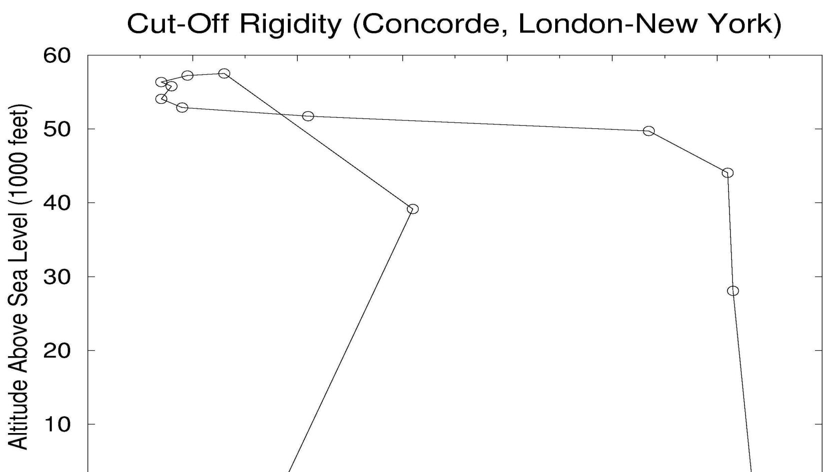

Figure 2: Rigidity Profile (London-New York, supersonic)

The study of the charge spectra of $Z \geq 2$ nuclei was included as an extension of these investigations. The ionisation threshold of the detectors and the experimental methods employed allowed observations down to energy losses of 5keV/μm. Cosmic ray primary and secondary nuclei in the Z range $2 \leq Z \leq 4$ were located primarily during the high magnification scanning phase of these studies. The criterion for selection was that a pair of cones exist (one on the top surface and one on the bottom surface) corresponding to the passage of the particle through at least one sheet of detector. This allowed the discrimination of the higher energy cosmic ray particles from the overwhelming background of short range recoils (typically R≤50μm). For instance, helium nuclei generally registered in one sheet only since their ionisation decreases rapidly with energy and falls below the observable threshold. The energy interval over which helium nuclei were observed and measured in this experiment was 7 MeV/n to 22 MeV/n, the former being defined by the minimum energy required to traverse one plate and the latter by ionisation threshold considerations. Nuclei with Z≥4 which traversed part or all of the detector stack were observable in several or all of the sheets. In order to facilitate following events from sheet to sheet it was required that the initial track picked up should have R≥2μm. This criteria, along with the consideration of the minimum energy required to traverse a single plate defined the energy intervals indicated in Table 1 for the nuclei.

The charge of the individual particles was determined in the usual manner using the etch rate gradient and calibrating the detectors with stopping protons and carbon ions.

3 Results

Table 1 shows the differential fluence of elements from helium to oxygen along with the energy intervals in which they are detected. Figure 3 shows a comparison of the experimental data and the predictions of the Siegen HITCODE programme which calculates particle fluxes at different depths in the Earth's atmosphere (Heinrich, 1977). The calculation was performed for solar minimum modulation. Differential energy spectra of the nuclei with charges Z=2 to Z=26 were calculated for different cut-off rigidities at different depths in the atmosphere. These spectra were summed for the total flight time from London to New York. The result is the time integrated fluence spectrum as a function of energy. These spectra are shown in the figure as lines. The energy intervals for which particles were detected in the experiment are shown by the black band on the plot.

Agreement is very satisfactory except in the case of the oxygen data. Possible losses of heavier events in the following through procedure used after event location in the initial plate are being investigated.

The significant change observed with respect to relative abundances at the top of the atmosphere is due to nuclear fragmentation in the Earth's atmosphere. These changes are well understood from the model calculation (Heinrich, 1977). In particular we note the good agreement of the fluence of the secondary elements such as Li, Be and B with those predicted.

Table 1:*Differential Fluence of Cosmic Ray Nuclei at Supersonic Altitude (London-New York)*

Nuclei	Energy Interval Detected	Differential Fluence Observed
	(MeV/n)	$(cm^2\ MeV/n)^{-1}$
He	7≤E≤22	$(3.43 \pm 0.49) \times 10^{-3}$
Li	8≤E≤60	$(1.24 \pm 0.50) \times 10^{-4}$
Be	10≤E≤150	$(3.06 \pm 1.53) \times 10^{-5}$
B	11≤E≤155	$(2.98 \pm 1.49) \times 10^{-5}$
C	13≤E≤250	$(4.07 \pm 1.36) \times 10^{-5}$
N	14≤E≤400	$(1.39 \pm 0.62) \times 10^{-5}$
O	15≤E≤800	$(5.46 \pm 2.73) \times 10^{-6}$

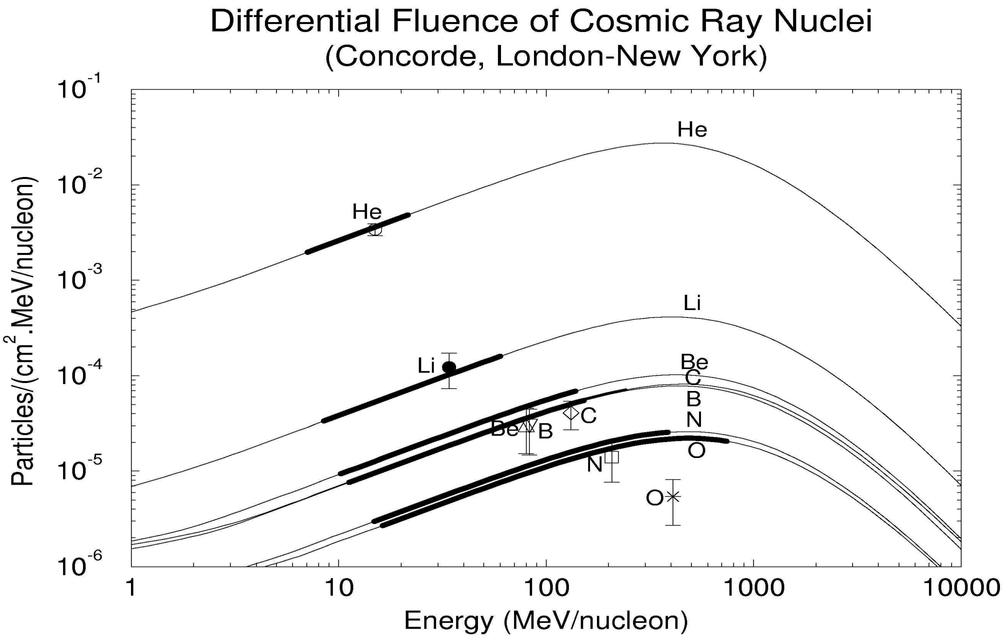

Figure 3: A comparison of experimental and theoretical results for cosmic ray nuclei at supersonic altitude (London-New York)

The contribution of these nuclei to the overall dose experienced by aircrew has been investigated and initial results show that it is approximately one per cent on the route discussed here.

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