MONITORING COSMIC RADIATION ON AIRCRAFT

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ABSTRACT

The Earth is constantly bombarded by cosmic radiation that can be either galactic or solar in origin. At aircraft altitudes, the radiation levels are much higher than at sea level and recent European legislation has classified aircrew as radiation workers. University College London is working with Virgin Atlantic Airways on a 3 year project to monitor the levels of cosmic radiation on long-haul flights. The study will determine whether models currently used to predict radiation exposure of aircrew are adequate. It will also try to determine whether solar flare activity can cause significant enhancement to the predicted doses.

1. DETAILS OF THE STUDY

The Mullard Space Science Laboratory (MSSL – the Department of Space and Climate Physics of University College London) has recently started a project to monitor the cosmic radiation in aircraft cabins.

The study will last for 3 years and is funded under PIPSS grant from the UK Particle Physics and Astronomy Research Council (PPARC) with Virgin Atlantic Airways (VAA) as the industrial partner. The UK National Physical Laboratory (NPL) and Civil Aviation Authority (CAA) are also collaborating in the study.

One of the drivers for this study was the requirement by the Council of the European Union for Member States to implement Directive 96/29/Euratom by 13 May 2000. Article 42 of the Directive imposes requirements relating to the assessment and limitation of air crews' exposure to cosmic radiation and the provision of information on the effect of cosmic radiation.

This investigation is designed to:

- Compare the measured dose to models used to predict crew radiation exposure
- Determine whether there are significant short-term excursions in the dose-rate caused by solar or geo-magnetic activity

The study is still in its early stages and this is a report of the work in progress.

2. THE NATURE OF COSMIC RADIATION

Cosmic radiation is the collective term for the radiation that comes from the Sun (the solar component) and from the galaxies of the Universe (the galactic component). Cosmic radiation consists of a complex mixture of types of radiation and their interactions in the atmosphere are similarly complex. Nevertheless, the Earth's atmosphere substantially shields the Earth from cosmic radiation, though doses of cosmic radiation are greater with increasing altitude.

Cosmic radiation particles may be electrically charged and so may be deflected by the Earth's magnetic field, it is for this reason that doses of cosmic radiation are greater at higher latitudes towards the Earth's magnetic poles. The deflection of cosmic radiation particles is least for higher energy particles and for particles of all energies travelling parallel to the magnetic field lines. The deflection is greatest for lower energy particles such that apart from exceptional solar events, the solar component of cosmic radiation is of no direct concern at aircraft altitudes.

The output of radiation from the Sun varies on an approximate 11 year cycle. At times of maximum solar output, associated with increasing numbers of sunspots, the magnetic field embedded within the Sun's radiation serves to deflect more of the galactic cosmic radiation component away from Earth. For this reason doses are about 20% lower than the mean value during maximum solar activity and about 20 % higher during solar minimum. Mainly, but not exclusively during solar maximum there is a small probability of a solar flare giving rise to exceptionally high numbers of energetic particles such that there are increased levels of cosmic radiation at aircraft altitudes.

A few very large proton flares occur each cycle, the largest known was in 1956. None of the flares have been recorded using an airborne monitor, and the doses quoted have been predicted using models.

3. HARMFUL EFFECTS OF THE RADIATION

All living things on Earth are exposed to a background level of radiation from naturally occurring substances.

Additionally, there may be further exposure from man-made sources such as medical x-rays. There is direct evidence that high levels of radiation are harmful to humans. It is believed that lower levels carry a risk that is in proportion to the dose.

Cosmic radiation is ionising, i.e. it can displace charged particles from atoms. This can lead to the disruption of molecules in living cells, although processes in the cell repair most of this damage.

4. DOSES FROM COSMIC RADIATION

The unit of measurement of absorbed dose of ionising radiation is the gray (Gy), where 1Gy = 1 J/kg. Equal absorbed doses of different types of radiation may have biological effects of different magnitudes. To account for this, the absorbed dose is multiplied by factors reflecting the radiation quality to obtain “dose equivalent” quantities which give a better estimate of risk. There are several such quantities. The one reported here, referred to simply as ‘dose’, is dose equivalent, expressed in sieverts (Sv), as measured by a particular instrument, a tissue equivalent proportional counter (TEPC). This is considered the most appropriate device for measuring cosmic ray ‘doses’ at aircraft altitudes.

In the UK the average background radiation dose is 2.2 millisieverts (mSv) per annum. Such background radiation is not taken into account when calculating occupational radiation exposure.

Cosmic radiation is made up of many different types of particles of a wide range of energies and consequently is difficult to measure to a high degree of accuracy. The dose equivalent rates increase with altitude up to a maximum at about 20 km (66,000ft), and with increasing latitude reaching a constant level at about 50°. The effective dose rate at an altitude of 8 km (26,000ft) in temperate latitudes is typically up to about 3 micro-Sv (μSv) per hour, but near the equator only about 1 to 1.5 μSv per hour. At 12 km (39,000ft), the values are greater by about a factor of two.

5. INSTRUMENTATION AND TECHNIQUE

A TEPC is designed to mimic human tissue and give a measure of dose equivalent to a few micrometres of tissue. The specific instruments used in this study are a prototype and a production model of the commercially available Hawk TEPC, supplied by Far West Technology, California.

The Hawk TEPC is ideal for this work [1,2], as the entire system fits into a small suitcase, 53 cm x 34 cm x 21cm, which can be stowed in a floor or overhead locker. One enhancement to the unit employed for this work involved replacing the existing power pack with heavy duty batteries enabling the instrument to collect data continuously for more that 2 weeks and record over twenty flights without interruption.

The monitor records the microdosimetric spectrum every minute, storing the data on a flash memory card. Later, aircraft position and altitude are combined with the TEPC data, making it possible to compensate for variations in dose due to altitude and latitude when looking for effects caused by solar phenomena.

Fig. 1 shows the combined data plotted against time for a flight between London and Johannesburg in April 2000 – the effects of altitude and latitude are clearly visible on the plot of *Total Counts.* (Note: local time shows the time corresponding to the aircraft longitude)

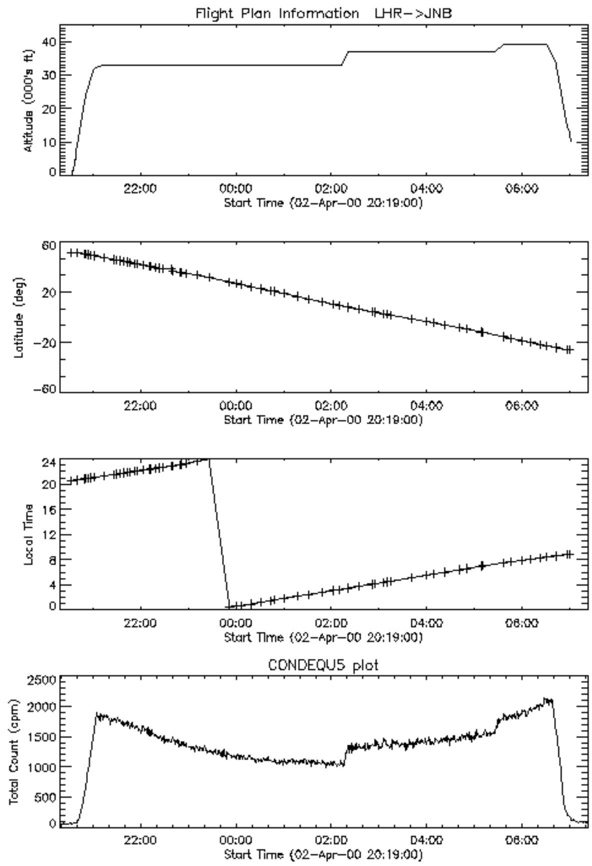

Fig. 1. Flight from London to Johannesburg

6. ROUTES AND MEASURED DOSES

In the study to date, the monitor has been carried on more than 100 flights using Virgin Atlantic A340 and B747 aircraft. Each route operated by Virgin will be monitored a sufficient number of times to determine the range of doses experienced on that route, as a function of flight profile, time of year and solar activity.

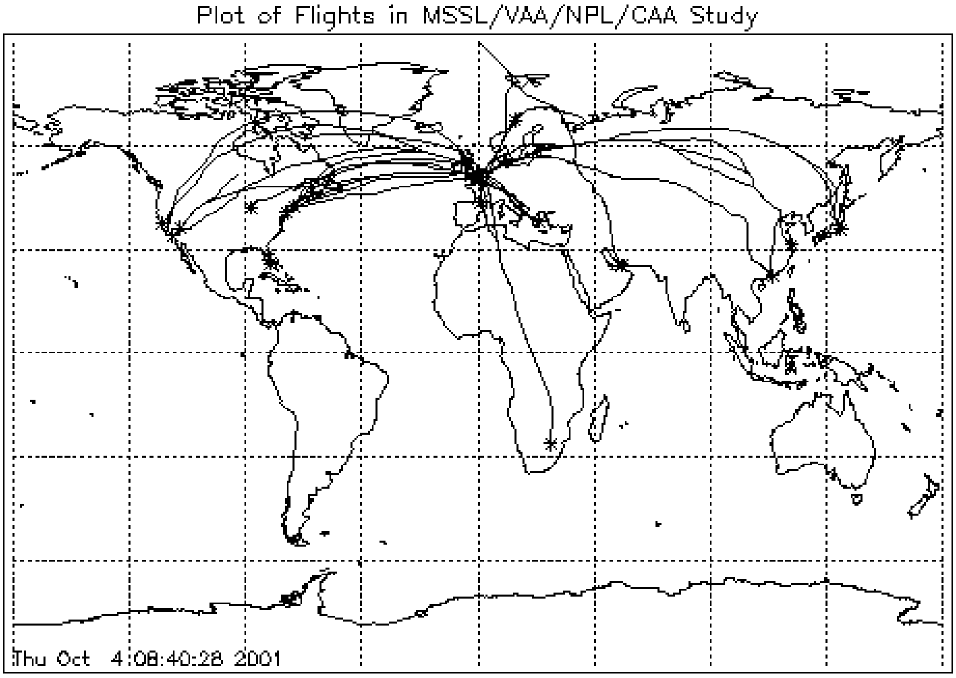

Fig. 2. Routes taken by flights for which details were available – destinations in the study are shown with "*". Note how flights to the Far East and South Africa follow almost exactly the same routes each time, whereas those to North America follow routes spread over a wide range of latitudes depending on weather conditions. To date, only a few measurements have been made in the southern hemisphere.

Table 1. Mean doses on routes operated by Virgin Atlantic Airways.

Route	No. of Flights	Mean Route Dose (μSv)	Std Dev (μSv)
London → Tokyo	4	52.5	3.7
Tokyo → London	3	59.3	2.7
London → Los Angeles	3	51.5	2.7
Los Angeles → London	2	47.9	1.5
London → San Francisco	2	46.8	1.4
San Francisco → London	2	38.0	4.5
London → Shanghai	2	43.4	3.3
Shanghai → London	1	56.8	-
London → Hong Kong	1	42.9	-
Hong Kong → London	1	55.0	-
London → Orlando	2	36.6	1.0
Orlando → London	2	28.9	1.3
London → New York	3	33.8	2.3
New York → London	2	29.8	1.2
London → Miami	2	30.8	4.7
Miami → London	1	27.7	-
London → Boston	6	30.7	3.1
Boston → London	4	25.9	3.2
London → Johannesburg	6	25.6	1.5
Johannesburg → London	5	25.0	3.1
London → Athens	4	11.4	0.9
Athens → London	4	13.0	0.6

The routes and number of sectors covered by the study, as of 29 June 2001, are summarised below. The monitor has also been taken on four flights on CAA aircraft, and on a test flight for Air Emirates (via the North Pole).

London → Athens	8
London → Boston	18
London → Chicago	2
London → Hong Kong	5
London → Johannesburg	11
London → Las Vegas	1
London → Los Angeles	7
London → Miami	8
London → New York	9
London → Newark	1
London → Orlando	5
London → San Francisco	4
London → Shanghai	4
London → Tokyo	12

Typical doses measured on routes flown by Virgin Atlantic are shown in Table 1 – the actual routes taken by the aircraft are shown in Fig. 2. Mean values (with their standard deviation) are given for sectors flown a number of times – flights affected by Forbush decreases (see below) have been excluded. The entries are listed in order of decreasing dose for the out-bound flight, showing the dramatic difference in exposure for similar length flights going to different parts of the world. For example, the flight to Johannesburg has approximately half the dose of a similar length flight to Tokyo because of the lower flux of cosmic radiation at lower latitudes where the cosmic ray cut-off rigidity is higher.

7. THE BASTILLE DAY FLARE

On 14 July 2000 (Bastille Day), the TEPC monitor was flown a few hours after the start of a large solar proton event, although it missed the initial pulse of particles.

Following any large event, the flux of cosmic rays reaching the Earth is reduced. These sudden intensity decreases, known as Forbush decreases, are associated with sudden increases in plasma density and magnetic flux emitted from the sun and are associated with "large" solar flares and interplanetary shock structures. The flights in the days following the Bastille Day flare were all affected by the Forbush decrease, and in each case a substantial reduction in the mean dose is observed – compare the doses in Table 2 with the average values given in the Table 1.

The data taken by the TEPC have been compared with data taken by the particle monitors on the ACE and GOES spacecraft, and ground-based neutron monitors. Fig. 3 shows some of these parameters plotted against time – the Forbush decrease that continued for several days after the event is not directly evident in the plot.

Table 2, Doses on routes for the flights following the Bastille Day flare.

Date	Route	Dose (µSv)
14/07/2000	London → Hong Kong	37.7
15/07/2000	Hong Kong → London	40.2
16/07/2000	London → Los Angeles	40.2
17/07/2000	Los Angeles → London	37.3
17/07/2000	London → New York	26.2
18/07/2000	New York → London	26.4
19/07/2000	London → Chicago	34.1
19/07/2000	Chicago → London	30.4
20/07/2000	London → Tokyo	43.5
21/07/2000	Tokyo → London	46.4
21/07/2000	London → Hong Kong	37.3

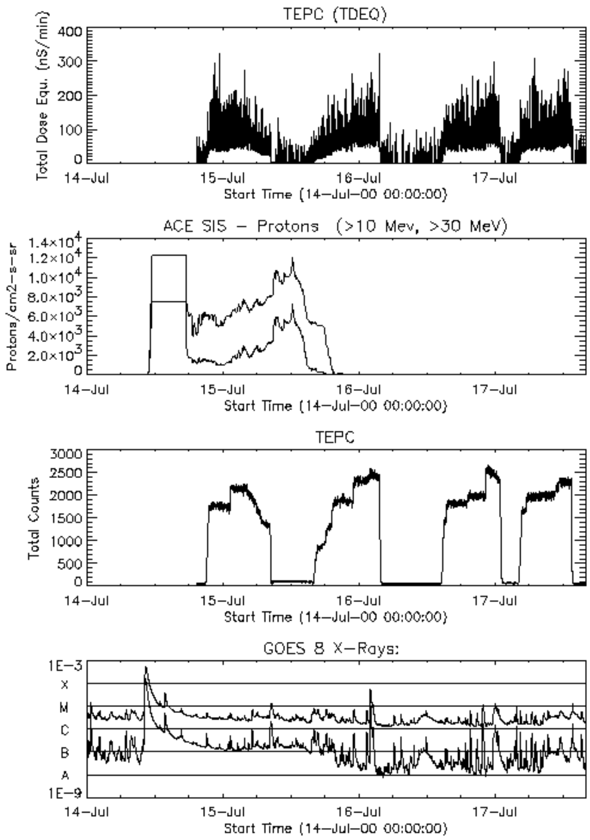

Fig. 3. Data taken by the TEPC following the Bastille day flare compared to other data.

8. REFERENCES

1. Lewis, B. J., et al. Aircrew Exposure from Cosmic Radiation on Commercial Airline Routes, Radiat. Prot. Dosim. Vol. 93, 293-314, 2001.
2. Taylor, G. C., et al. The Evaluation and Use of a Portable TEPC System for Measuring In-Flight Exposure to Cosmic Radiation, Radiat. Prot. Dosim., in press, 2001.