Solar Particle Effects in Aircrew Dosimetry

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Neutron Measurement Workshop

26th October 2006
• Overview of aircrew exposure to cosmic radiation
• NPL’s involvement in aircrew dosimetry
• The origins of solar particle events (SPEs)
• The dosimetry of SPEs
• NPL’s involvement in measuring SPE doses
In-Flight Exposure to Radiation

Air crew average occupational exposure:

* Short haul: ~2 mSv/y
* Long haul: ~4 mSv/y

(average UK background: 2.2 mSv/y)

* Average nuclear worker: <1 mSv/y

Since May 2000 airlines in the EU must assess the radiation exposure of air crew
CAA / MSSL / NPL / VAA
Collaborative Partnership 2000 - 2004

Objectives:
Fly detectors (TEPCs) on commercial aircraft;
Compare radiation dose measurements with predictions from computer codes used by airlines,
e.g. CARI, EPCARD, SIEVERT
Global Dose Rate Map

The Space Weather Multimedia CD ROM

http://www.df5ai.net/ArticlesDL/SpaceWeatherCD/SpaceWeatherCD.html

Effective Dose Rate in μSv/h
(39,000 ft)

μSv/h

0.25
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
9.0
9.5
10.0
10.5
11.0
11.5
12.0

Longitude in Degree

Latitude in Degree
Performance of CARI 6 vs TEPC Mmts for ANZ Routes

\[ C6.E = (-0.13 \pm 0.33) + (1.154 \pm 0.023) \times \text{TEPC.H} \]
### Comparison of Codes with TEPC Measurements

<table>
<thead>
<tr>
<th>Flight</th>
<th>Flight Code</th>
<th>Ambient Dose Equivalent (µSv)</th>
<th>TEPC</th>
<th>CARI-6</th>
<th>SIEVERT</th>
<th>EPCARD</th>
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</thead>
<tbody>
<tr>
<td>Lon-S/H</td>
<td>17180100</td>
<td>45.7</td>
<td>36.5</td>
<td>52.9</td>
<td>46.5</td>
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<td>Lon-JFK</td>
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<td>38.3</td>
<td>38.8</td>
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<tr>
<td>Lon-HK</td>
<td>14150700</td>
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<td>33.4</td>
<td>47.3</td>
<td>39.7</td>
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<tr>
<td>HK-Lon</td>
<td>15160700</td>
<td>40.2</td>
<td>33.2</td>
<td>48.3</td>
<td>46.1</td>
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<tr>
<td>Lon-LA</td>
<td>16170700</td>
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<td>42.6</td>
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<td>51.5</td>
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<tr>
<td>LA-Lon</td>
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<td>37.3</td>
<td>34.4</td>
<td>47.6</td>
<td>46.6</td>
<td></td>
</tr>
</tbody>
</table>

**Accuracy**
- < 10%
- 10% - 20%
- 20% - 30%
- >30%
The Solar Cycle and Atmospheric Radiation Levels

Ground-based Cosmic Ray Monitor

#Sunspots
The Sun’s Magnetic Field

Source/Credits: ESA / NASA
‘Quiet’ Sun v ‘Active’ Sun

Source/Credits: Solar & Heliospheric Observatory (SOHO).
SOHO is a project of international cooperation between ESA and NASA.
Bastille Day Event
July 14th 2000

Source/Credits: Solar & Heliospheric Observatory (SOHO).
SOHO is a project of international cooperation between ESA and NASA
Disruption of Earth’s Magnetic Field

Source/Credits: ESA / NASA
Issues with CR Dose Predictions

Factors Underlying GCR Dose Prediction
• Galactic Cosmic Ray field is reasonably constant
• Modulating effects of Solar Activity reasonably well understood
• Plenty of measurements for comparison

Factors Underlying SPE Dose Prediction
• SPE fields vary widely
• Modulation effects of Solar Activity unpredictable
• Very few measurements for comparison
Fig. 2. Derived spectra of peak fluxes for the 3 solar proton events are compared with the solar maximum cosmic ray spectrum.
Time-Dependence of SPE Spectra

CALCULATIONS AND OBSERVATIONS OF SOLAR PARTICLE ENHANCEMENTS TO THE RADIATION ENVIRONMENT AT AIRCRAFT ALTITUDES
C.S. Dyer, F. Lei, S. N. Clucas, D. F. Smart, M. A. Shea

Fig. 1. Solar proton spectra derived at several times during the 29 September 1989 event show softening with time. Comparison is made with a spectrum derived by Lovell et al. (1998).
Worst-case exposure for typical CDG – LAX flight
Exposure Calculations for Solar Particle Events
Previous Attempts to Measure SPE doses

GOES 10 Satellite
Previous Attempts to Measure SPE doses
Previous Attempts to Measure SPE doses

Moral: Never put all your eggs in one basket!
‘FlareWatch’

Aim: To fly small, robust instruments (THERMO EPD-N2s) on multiple aircraft

Partners: BA (probably!)

Launch: Spring 2007 (?)
Summary

SPEs - Usually caused by Coronal Mass Ejections (often associated with Solar Flares).

CMEs - Massive bursts of particles catapulted into space by ‘magnetic whiplash’
Not a problem unless CME trajectory results in a collision with the Earth
Not usually as energetic (i.e. penetrating) as GCR, but much higher fluences ($\times 10^5$ more)

GLEs - Instantaneous dose rates can increase 100-fold or more at aircraft altitudes
Associated magnetic storms can alter local earth potentials (Canadian blackouts, 1859 event!)
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Variation in Neutron Spectrum with Proton Energy

Proton-Induced Neutron Spectra at an Atmospheric Depth of 200 g.cm$^{-2}$

Group Fluence per Source Proton

Neutron Energy (MeV)

- 100 MeV
- 200 MeV
- 300 MeV
- 400 MeV
- 500 MeV
- 600 MeV
- 700 MeV
- 800 MeV
- 900 MeV
- 1 GeV
Variation in Photon Spectrum with Proton Energy

Proton-Induced Photon Spectra at an Atmospheric Depth of 200 g cm$^{-2}$

Group Fluence per Source Proton

Photon Energy (MeV)
The Solar Cycle

22 Cycles in 242 years: 11 years per cycle
Air crew have **higher** occupational radiation exposures than typical nuclear workers.

The exact exposure depends on **altitude**, **latitude** and **duration** of a given flight, as well as the **solar activity**.

NPL has collaborated in a massive in-flight measurement programme to demonstrate that **software** used to calculate crew doses **performs reasonably well** (long-term).

**Further Work** under way in the area, via collaborations with MSSL and SELEX (TEPC development) BA (“Flarewatch” solar particle event monitoring).
Michelson doppler Imager
Typical Route Doses for Solar Max (2000)

Route Doses for 83 Flights with Original TEPC

Measured Dose Equivalent (uSv)

Destination

- Boston
- Miami
- New York
- Tokyo
- Los Angeles
- Athens
- Hong Kong
- J'burg
- Shanghai
- Las Vegas
- Orlando
- Chicago
- San Francisco
Quality Factors for 83 Flights with Original TEPC

Mean Quality Factors

Quality Factors for 83 Flights with Original TEPC
Questions?

Credits

Animations: ESA / NASA
Images: The Space Weather Multimedia CD ROM
http://www.df5ai.net/ArticlesDL/SpaceWeatherCD/SpaceWeatherCD.html