Air Crew Exposure to Cosmic Rays – EPCARD Solution - Part I –

Vladimir Mares and Thomas Maczka
HELMHOLTZ ASSOCIATION

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  • Earth and environment
  • Health
  • Biology
  • Aeronaautics, space and transport

Hermann Ludwig Ferdinand von Helmholtz

Helmholtz (1821 – 1894) was one of the last true universal scholars whose work embraced all the sciences, as well as philosophy and the fine arts.

He founded the Physikalisch-Technische Reichsanstalt (PTR), the world’s first scientific research center outside university sector and counts as a predecessor to the Helmholtz Association.

http://www.helmholtz.de/en/helmholtz_centres_networks/helmholtz_centres/
http://www.helmholtz-muenchen.de

ISS Institute of Radiation Protection

The Institute  Research  Publications  Service  Courses  Teaching

EPCARD

Individual Dosimetry
We assess radiation exposures by computer models...

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Highlights
Lung cancer risk after radon exposure in the Eldorado uranium miners
Evidence for formation of DNA repair centers in human cells

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WHY IS AIR CREW DOSIMETRY IMPORTANT FOR TODAY AND TOMORROW
How many planes are there each day?

On average, there are about 90,000 flights per day; worldwide at any given time, there are between 8,000 and 13,000 planes in the air; nearly a million passengers in air any time. An aircraft currently arrives or leaves Heathrow every 45 seconds. So approximately 960 flights a day land at Heathrow which translates to 350,400 per year.

V. Mares and T. Maczka, 5th ASISTIM USER DAY, Hannover, 10-11 Sep. 2015
Polar Routes

More efficient operations
• New nonstop routes
• Avoid hubs
• Lower fuel burns
• Shorter trip times
• No intermediate fuel stop
• Increased payload potential

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http://www.snipview.com
Air crews are exposed to a relatively high effective dose from GCR. Crews of future high-altitude commercial aircraft will be even more exposed.
Radiation Dose Examples

Canadian Nuclear Safety Commission (http://nuclearsafety.ge.ca)

Effective Dose

- In Germany 2.4 mSv
- Germany 0.02 mSv

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<table>
<thead>
<tr>
<th>Destination</th>
<th>Effective Dose Range* [μSV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frankfurt - Las Palmas de Gran Canaria</td>
<td>10 - 18</td>
</tr>
<tr>
<td>Frankfurt - Johannesburg</td>
<td>18 - 30</td>
</tr>
<tr>
<td>Frankfurt - New York</td>
<td>32 - 75</td>
</tr>
<tr>
<td>Frankfurt - Rio de Janeiro</td>
<td>17 - 28</td>
</tr>
<tr>
<td>Frankfurt - Rome</td>
<td>3 - 6</td>
</tr>
<tr>
<td>Frankfurt - San Francisco</td>
<td>45 - 110</td>
</tr>
<tr>
<td>Frankfurt - Santo Domingo (Dom. Rep.)</td>
<td>30 - 65</td>
</tr>
<tr>
<td>Frankfurt - Singapore</td>
<td>28 - 50</td>
</tr>
<tr>
<td>Frankfurt - Tokyo</td>
<td>45 - 110</td>
</tr>
</tbody>
</table>

* The variation is mainly due to the effect of cruising altitudes and solar cycle.
## Radiation Dose Quantities

<table>
<thead>
<tr>
<th>Dose Quantities</th>
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</thead>
<tbody>
<tr>
<td><strong>Absorbed Dose</strong></td>
</tr>
<tr>
<td>Energy &quot;deposited&quot; in a kilogram of a substance by radiation</td>
</tr>
<tr>
<td><strong>Equivalent Dose</strong></td>
</tr>
<tr>
<td>Absorbed dose weighted for the degree of the effect of different radiation</td>
</tr>
<tr>
<td>(radiation weighting factor $w_R$ (20 - 1))</td>
</tr>
<tr>
<td><strong>Effective Dose</strong></td>
</tr>
<tr>
<td>Equivalent dose weighted for susceptibility to effect of different tissues</td>
</tr>
<tr>
<td>(tissue weighting factor $w_T$ (0.20 - 0.01))</td>
</tr>
</tbody>
</table>
Monitored persons in National Dose Register in Germany, 2013
Average annual effective dose per person

Strahlenschutzüberwachte Personen in Deutschland (2013): ca. 400.000

G. Frasch, Bundesamt für Strahlenschutz, 2014
Collective dose of all monitored persons in Germany 2013

Kollektivdosis strahlenschutzüberwachter Personen (2013): ca. 103 Pers.-Sv

G. Frasch, Bundesamt für Strahlenschutz, 2014

Fliegenderes Personal 73%
Air Crew

Natural Radiation Sources
Nat. rad. Quellen <1%

Medcin 12%
Medizin

Nuclear Technique
Kerntechnik 4%

Industrie 10%
Forschung, Entwicklung <1%
Research

80 person-Sv
Effective Dose Interval in mSV

G. Frasch, Bundesamt für Strahlenschutz, 2014

Personnel using ionising radiation

Fliegendes Personal

Air Crew

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Based on recommendations of the International Commission on Radiological Protection (ICRP) - 1990


Each Member State shall make arrangements for parties operating aircraft to take account of exposure to cosmic radiation of air crew who are liable to be subject to exposure to more than 1 mSv per year

German Regulation on Radiological Protection¹, effective by 20 July 2001 (Regulation for the realisation of the European Council Directive 96/29/EURATOM on radiological protection) to be realised by 1 August 2003, the latest.


Chapter 4: Cosmic Radiation

§103 Protection of aircrew against exposition by cosmic radiation

Aircraft undertakings shall determine the effective dose if it is likely that the effective dose exceeds 1mSv per year. The result shall be available 6 months after exposure, the latest.
In 1912 the Austrian scientist Victor Hess discovered in manned balloon flights reaching altitudes above 5000 m that the electrical conductivity of air is significantly enhanced above approximately 1000 m. Furthermore, no differences were found between day and night.
Cosmic radiation in the Earth’s atmosphere

- “Radiation from above” discovered by Victor Hess in 1912
- Robert Millikan in the 1920s gave it the name cosmic rays
- In 1930 Walther Bothe and Werner Köhlorster discovered that cosmic rays are high-energy charged particles
- Cosmic rays are high-energy particles that travel throughout the Milky Way Galaxy
- Source is believed to be exploding stars (supernovae) or black holes
- Primaries = particles arriving at the top of the Earth’s atmosphere (87% protons, 12% He ions, 1% heavy ions)
- Secondaries = created by collisions with atmospheric nuclei (nitrogen, oxygen)
Natural Shielding of Cosmic Rays

- « solar shielding » – time
  - solar activity, solar wind
  - 11 year sunspot cycle
  - radiation is MAX at sunspot MIN

- « geomagnetic shielding » – geographic position
  - magnetic field deflects charged particles back into space
  - dose at poles is about 5-10 times higher than at equator at 20 km

- « shielding by air » – barometric altitude
  - mass thickness of 1030 g/cm² at sea level and 55 g/cm² at 20 km
  - dose at 20 km is about 200-times higher than at sea level

http://www.newworldencyclopedia.org

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The planetary system is shielded against GCR by the solar field, depending on solar activity - sunspots number

Monthly averaged sunspot numbers SSN (lower red curve) and counts measured by the Oulu Neutron Monitor (upper blue curve), for solar cycles 20 through 24. (SSN from SILSO data/image, Royal Observatory of Belgium, Brussels)

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Worldwide Network of Neutron Monitors (NM)

NM’s provide:
- counting rates only
- no information about fluence, energy and dose of neutrons

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« geomagnetic shielding » – geographic position

World map of vertical effective cut-off rigidity $R_c$ in GV

Calculated with MAGNETOCOSMICS using the IGRF-11 model and the model by Tsyganenko for the description of the outer magnetosphere (C. Pioch, 2012, PhD Thesis)
Earth’s North Magnetic Pole is racing toward Russia

- has moved 1,100 km during 20th century
- since 1970 ist rate of motion has accelerated from 9 km/year to ~50 km/year
- almost 40 miles (64 km) a year
- will reach Siberia by the year 2050.
In EPCARD ver.3.34
D.F.Smart & M.A.Shea for epoch 1990.0

In EPCARD.Net
MAGNETOCOSMICS* for epoch 2005.0

* calculated with MAGNETOCOSMICS using the IGRF-10 model and the model by Tsyganenko for the description of the outer magnetosphere (R.Bütikofer, E.O.Flückiger, L.Desorgher)

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Effective dose rate world map according to EPCARD data at typical flight level FL370 (37,000 feet, i.e. 11.3 km) and April 2005 (lower solar activity).
Air crews are exposed to a relatively high effective dose from GCR.

- Mass thickness of 1030 g/cm² at sea level and 55 g/cm² at 20 km.
- Dose at 20 km is more than about 200-times higher than at sea level.

Effective Dose per hour [µSv/h] vs. Altitude [km]:

- Concorde (18,000 m) at 20 km.
- Lear Jet (15,000 m) at 15 km.
- Boeing 747 (12,000 m) at 10 km.
- Mount Everest (8850 m) at 8 km.
- Mont Blanc (4807 m) at 5 km.
- Lhasa, Tibet (3650 m).
- Mexico City (2240 m).
- Zugspitze (2962 m).
- Munich (530 m).
- Hamburg (0 m).

>>> Rule of thumb <<<

5 - 7 µSv/hr in 10 km.
Relative contribution to effective dose rate as function of altitude for various altitudes for time period close to solar minimum and for pole regions.

V. Mares according to FLUKA data of S. Roesler

UFS Schneefernerhaus at Zugspitze mountain

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Influence of Aircraft Shielding on the Aircrew Exposure Model of Airbus-340 in FLUKA


![Graph showing ambient dose equivalent rate (µSv/h) vs. Rows]

- free in atmosphere

- full aircraft – 278 passengers, baggage, cargo, fuel
- full aircraft – 278 passengers, baggage, cargo, no fuel
- aircraft with only 23 passengers, reduced baggage, full fuel

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CONTINUOUS MEASUREMENTS ON THE EARTH SURFACE
Mt. Chacaltaya, Bolivia
5395 m.a.s.l.

Mt. Zugspitze, Germany
2962 m.a.s.l.

Experimental Verification and Calculation of Aviation Route Doses,
H. Schraube, V. Mares, S. Roesler, W. Heinrich,
Radiation Protection Dosimetry Vol. 86, No.4,

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UFS Zugspitze mountain
2,650 m; cut-off ~4 GV

Ny-Ålesund in Spitsebergen
0 m; cut-off ~0 GV
UFS Schneefernerhaus at Zugspitze (2650 m.a.s.l.)
Jan 2010 – Jun 2014

Average ambient dose equivalent rate: $66.2 \pm 6.2 \text{nSv/h}$

Average neutron fluence rate: $\sim 800 \text{ m}^{-2}.\text{s}^{-1}$
History

1990 – recommendation of the International Commission on Radiological Protection (ICRP)

1993 – D. Regulla and J. David: Measurements of cosmic radiation on board Lufthansa aircraft on the major intercontinental flight routes

H.G. Paretzke and W. Heinrich: Radiation Exposure and Radiation Risk in Civil Aircraft

1996 – D. Regulla and H. Schraube: Radiation exposure of aircrews in civil aviation


1999 – EPCARD - European Program Package for the Calculation of Aviation Route Doses

2000 – EPCARD v.3.0 and v.3.1

2002 – EPCARD v. 3.2

2003 – EPCARD v. 3.3

2003 – EPCARD v. 3.34 – officially approved by the German Aviation Authority (LBA) and the National Metrology Institute (PTB)

2006 – EPCARD v. 4.0 – internal usage

2007 – EPCARD.Net v. 5.3.0 "Evaluation Version"

2010 – EPCARD.Net v 5.4.3 officially approved by the German Aviation Authority (LBA)

2015 – EPCARD.Net v. 5.5.x "Certificate Candidate" - will be sent to certification in 2015
SECONDARY SPECTRA OF GCR AT FLIGHT LEVEL
11.43 km, cut-off rigidity 0 GV, solar minimum (based on data of W. Heinrich)

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Fluence rates of secondary cosmic ray particles at various altitudes in the Earth’s atmosphere calculated with FLUKA Monte Carlo code (Roesler, 2002) for pole (on the left side) and equator regions (on the right side) and a time period close to solar minimum.
Calculated effective doses for flight routes from Munich (MUC), New York (JFK), Sydney (SYD) and Kuala Lumpur (KUL) for the time period of solar minimum. The flights are sorted according to flight duration.
With this computer program you may calculate online the dose, which you would receive along a specified flight due to cosmic radiation. Additionally, you may determine the dose, which is accumulated during a stay of one hour at any flight position in the atmosphere.

New EPCARD.Net

EPCARD.Net version 5.4.1 was approved for official use for aircrew dose determination by the German Aviation Authority (LBA) and the National Metrology Institute, Physikalisch-Technische Bundesanstalt (PTB) on April 23rd, 2010. [Read more...]
Effective Dose Rate in 11.3 km

Calculated with EPCARD online version at: [http://www.helmholz-muenchen.de/epcard](http://www.helmholz-muenchen.de/epcard)

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THANK YOU FOR ATTENTION