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Radiation Exposure in Aviation Altitudes During Quiet and Solar Storm Periods

Second European Space Weather Week, 14-18 November 2005
ESTEC, Noordwijk, The Netherlands

Peter Beck

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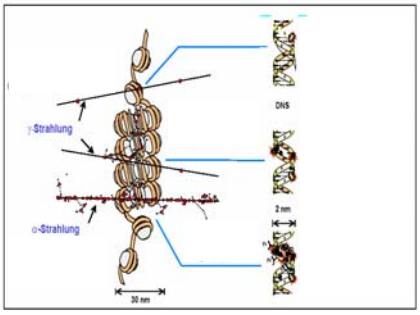
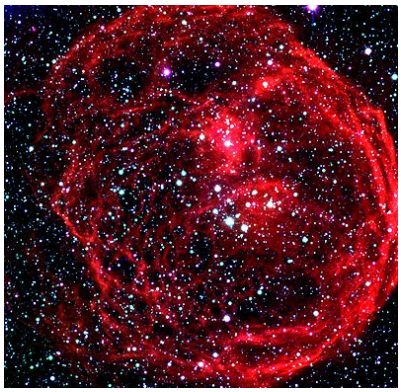
Early Influence by Cosmic Radiation





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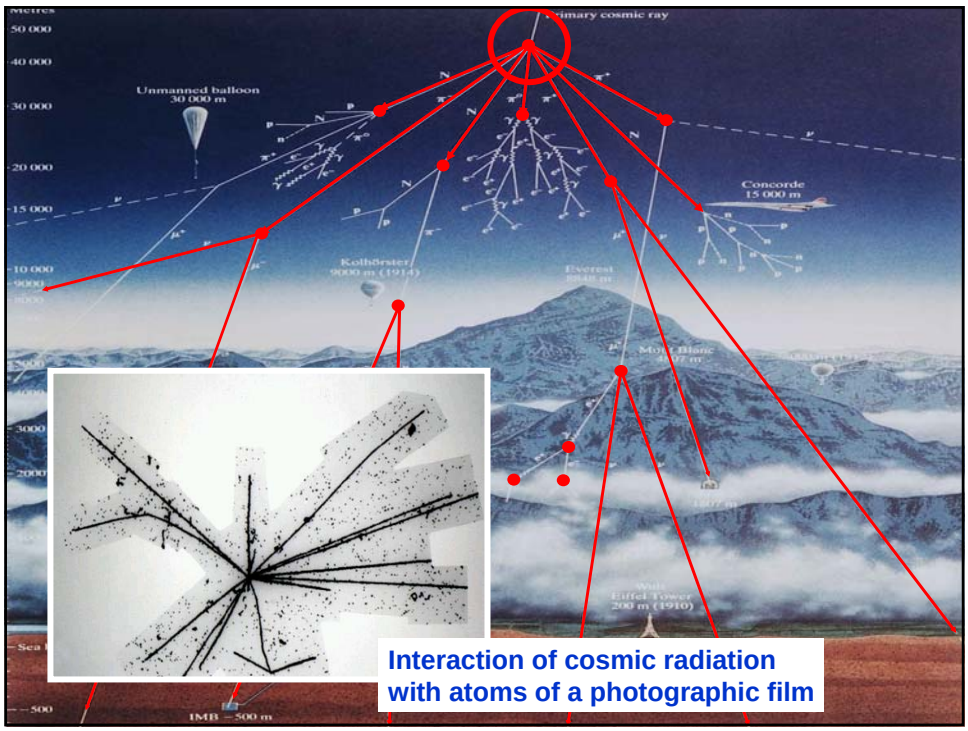
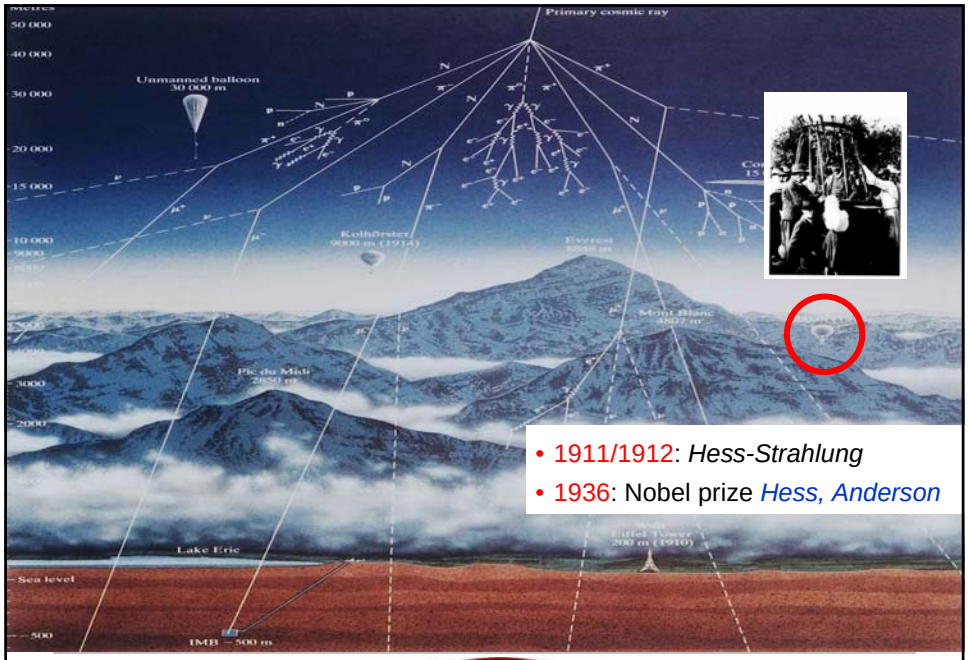


Interaction of cosmic radiation with atoms of a photographic film



- 1911/1912: *Hess-Strahlung*
- 1936: Nobel prize *Hess, Anderson*

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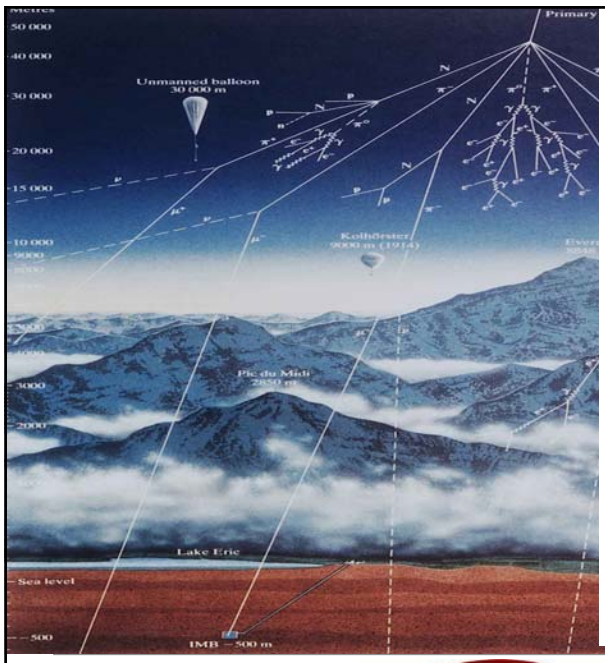
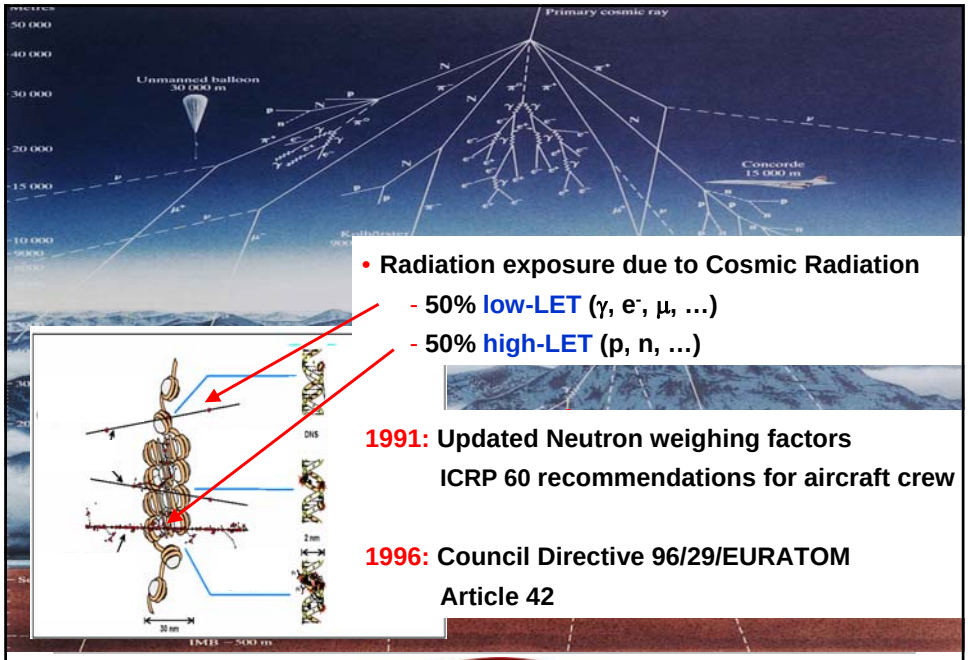


SCR particles in one second

- 5,000 per 1 m²
- 400 / 4,000 => human body
- 400 => laptop

- 250 / 2,500 => human body
- 250 => laptop

- 10 / 100 => human body
- 10 => laptop
- 1,000 => car



- **Radiation exposure due to Cosmic Radiation**
  - **50% low-LET (γ, e⁻, μ, …)**
  - **50% high-LET (p, n, …)**

1991: Updated Neutron weighing factors
ICRP 60 recommendations for aircraft crew

1996: Council Directive 96/29/EURATOM
Article 42

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Studies & European Research 1990-2004: e.g. ACREM / DOSMAX

- ANPA / Italy
- ARCS / Austria
- AUA / Austria
- Brazilian Airforce / Brazil
- CERN /Swiss
- DIAS / Ireland
- DLH AG / Germany
- DLR / Germany
- GSF / Germany
- INFN / Italy
- IPSN / France
- NPI / Czech
- NRPB / UK
- PTB / Germany
- SSI / Sweden
- TU - Graz / Austria
- Uni München / Germany
- University of Siegen / Germany
- VARIG / Brazil

EURADOS in-flight radiation data base
- 368 In-flight investigations
- 10 526 Data sets analyzed

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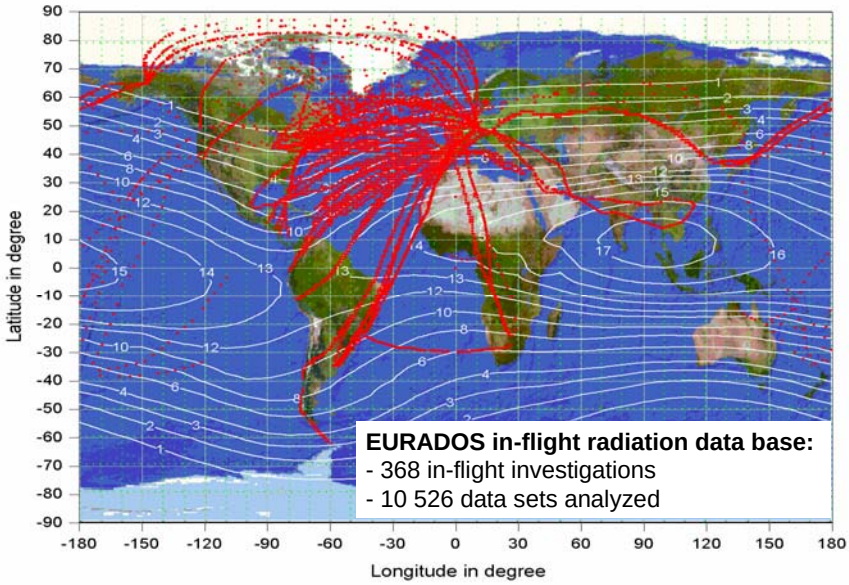
Considered In-Flight Investigation May 1992 – April 2003



EURADOS in-flight radiation data base:
- 368 in-flight investigations
- 10 526 data sets analyzed

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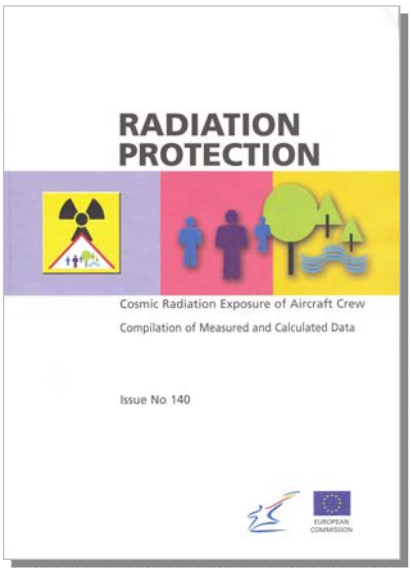
2004: EURADOS
EC-Report



ISO-Standard:

Dosimetry for exposure to cosmic radiation in civil aircraft.

EURADOS Working Group 5 on Aircraft Crew Exposure

D.T. Bartlett[1], P. Beck[2], P. Bilski[3], J.-F. Bottollier-Depois[4], L. Lindborg[5] (Chairman from 2003), H. Schraube[6], F. Spurný[7] and F. Wissmann[8], E. Felsberger[9] (resigned in 2002), W. Heinrich[10], B. Lewis[11], D. O´Sullivan[12], G. Reitz[13], U. Schrewe[14] (Chairman 2000 to 2002), and L. Tommasino[15], G. Dietze[8] for Article 31, I. McAulay[16] for Article 31, J. Siedenburg[17] (2004) and A. Ruge (2000 –2003) for JAA, K. Schnuer[18] for EC and K. Ulbak[19] for Article 31.

Contributions were also received from:
J.C. Saez-Vergara[(20)], H. Roos[(21)], G.A. Taylor[(22)], R. Grillmaier[(23)], W. Friedberg[(24)], K. O'Brien[(25)], M. Pelliccioni[(26)], B. Wiegel[(8)] and their colleagues.

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(2) ARC Seibersdorf Research (ARCS), Seibersdorf, Austria
(3) Institute of Nuclear Physics, Krakow, Poland
(4) Institute for Radiation Protection and Nuclear Safety (IRSN) , Paris, France
(5) Swedish Radiation Protection Authority (SSI), Stockholm, Sweden
(6) Forschungszentrum für Umwelt und Gesundheit (GSF), Institut für Strahlenschutz, Neuherberg, Germany
(7) Nuclear Physics Institute, Academy of Sciences of Czech Republic, Prague
(8) Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
(9) IASON Labormedizin GesmbH. & Co KG, Austria
(10) Universität, Siegen, Germany
(11) Royal Military College of Canada (RMC), Kingston, Ontario, Canada
(12) Dublin Institute for Advanced Studies (DIAS), Dublin, Ireland
(13) Deutsches Zentrum für Luft und Raumfahrt (DLR), Institut für Luft- und Raumfahrtmedizin, Köln, Germany
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(17) Central Joint Aviation Authority (JAA), Hoofdorp, The Netherlands
(18) European Commission, DG TREN H4, Luxembourg
(19) Statens Institut for Straalehygiejne (SIS), Knapholm, Denmark
(20) CIEMAT, Dosimetría de Radiaciones, Madrid, Spain
(21) Radiobiologisches Institut, Ludwig-Maximilians-Universität München, Germany
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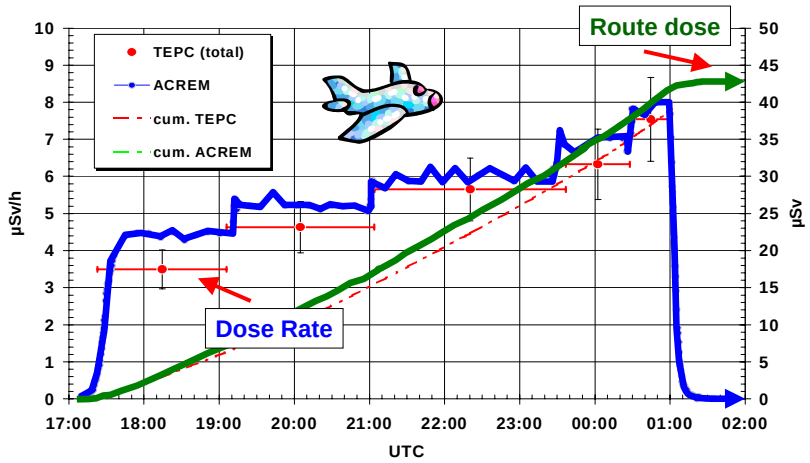
Cosmic Radiation Exposure of Aircraft Crew:
Compilation of Measured and Calculated Data

Contents

Verification of Calculation Codes



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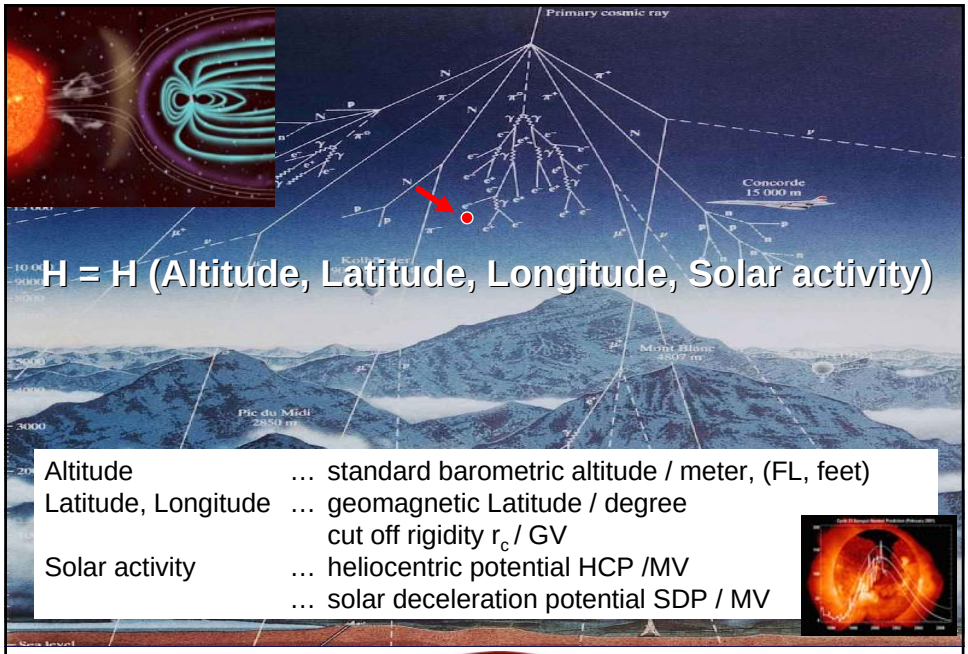

H = H (Altitude, Latitude, Longitude, Solar activity)

Altitude	…	standard barometric altitude / meter, (FL, feet)
Latitude, Longitude	…	geomagnetic Latitude / degree
		cut off rigidity r_c / GV
Solar activity	…	heliocentric potential HCP /MV
	…	solar deceleration potential SDP / MV

Analyzed In-Flight Investigations

Institute	Primary investigator	Dose assessment method	Number of data[1]	Time Period
APAT	Tommasino	TEPC (tissue equivalent proportional counter) and other active instruments	55	1997
ARCS	Beck	TEPC and other active instruments	1767	1997 – 2003
CIEMAT	Saez-Vergara	TEPC and other active instruments	5680	2001 – 2002
GSF	Schraube, Regulla	active instruments	308	1992 – 1993
IRSN	Bottollier	TEPC	49	2002
NPI	Spurny	Si-spectra dosemeter (MDU-Liulin)	811	2001
NPL	Taylor	TEPC	146	2000-2003
NRPB	Bartlett	track detectors and TLDs	19	1997 – 2003
PTB	Schrewe	active instruments	1240	1997 – 1999
PTB	Wiegel	Bonner Spheres, Ionization Chamber	43	1998
RMC	Lewis	TEPC	342	1999
SSI	Lindborg	TEPC	66	1998 – 2003

[1] EURADOS In-Flight Radiation Data Base.

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Dose Assessment Methods During In-Flight Investigations

Abbreviation	Dose assessment method measurement / calculation	Measurement intervals
NM+IC (ARCS)	Combined neutron monitor (NM) LB6411 and ionization chamber (IC) RSS [BEC99a], [BEC99b]	5 min
NMX+IC (PTB)	Combined neutron monitor NE-NM2 with lead converter (NMX) and ionization chamber [SRE99a], [SRE99b]	5 - 20 min
ACREM (ARCS)	Combined GM detector and transport code calculations [BEC99a], [BEC99b]	5 min
NMX+Halle(GSF)	Combined neutron monitor NE-NM2 with lead converter (NMX) and low level scintillation detector DLM7908 [REG93], [REG96]	6 min
TEPC-log (ARCS)	TEPC detector, 12 cm sphere, logarithmic amplifier [BEC99a], [BEC99b], [BEC04]	30 – 60 min
TEPC (SSI)	**TEPC instruments based on the variance method [KYL01]**	**30 - 60 min**
NMX+IC (CIEMAT)	Combined neutron monitor with tungsten converter (NMX) SWENDI-2 and ionization chamber (IC) RSS [SAE02] [ROM04] [SAE04a] [SAE04b]	5 min
LIULIN (NPI)	Si-Spectra-dosemeter developed originally for space (MDU-Liulin) [SPU03]	30 min
Track Detector (NRPB)	Box with 36 PADC and 30 TL dosemeters [BAR00], [BAR01], [BAR03]	16 × 120 min
TEPC (NPL-PPARC)	TEPC (HAWK) [TAY02]	30 min
EPCARDv3.2	European Program Package for the Calculation of Aviation Route Doses [SRA02]	single point calculation
TEPC (IRSN)	TEPC (HAWK) [BOT04]	30 min
TEPC (APAT)	TEPC (HANDI) [TOM99], [CUR01a], [CUR01b]	60 min
NMX+IC (APAT)	Combined neutron monitor LINUS with tungsten converter (NMX) and ionization chamber RSS (IC) [TOM99]	5 min
BSS+IC (PTB)	Bonner Spheres (BSS) and ionization chamber (IC) [WIE02], [BEC99a].	30 - 60 min

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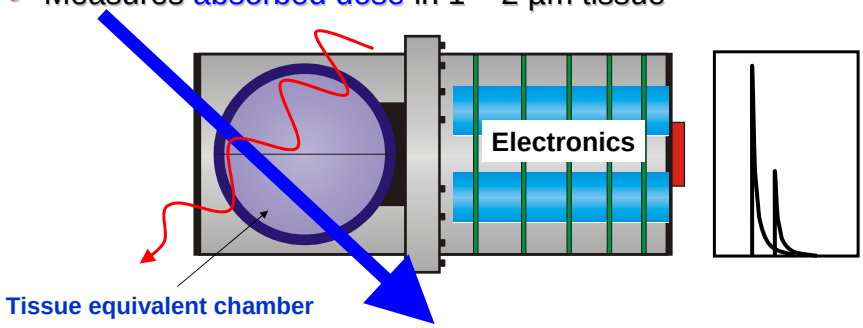
A Tissue Sensitive Instrument

- TEPC (Tissue Equivalent Proportional Counter)
- Measures absorbed dose in 1 – 2 µm tissue



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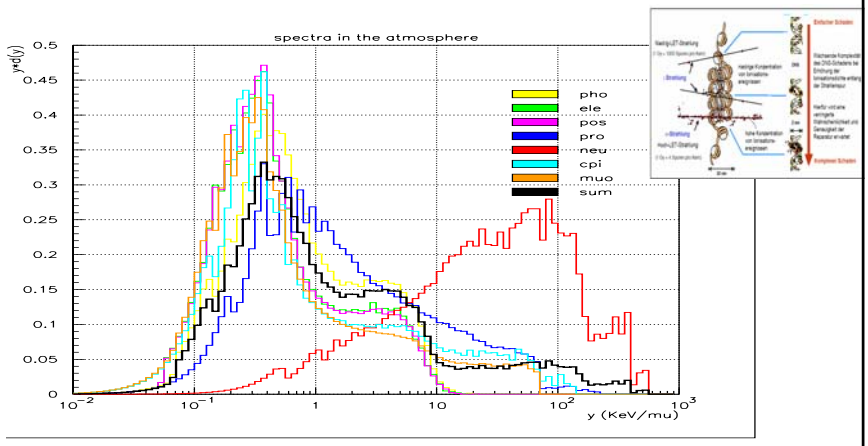
TEPC Simulation by FLUKA
Microdosimetric Spectra in CR field



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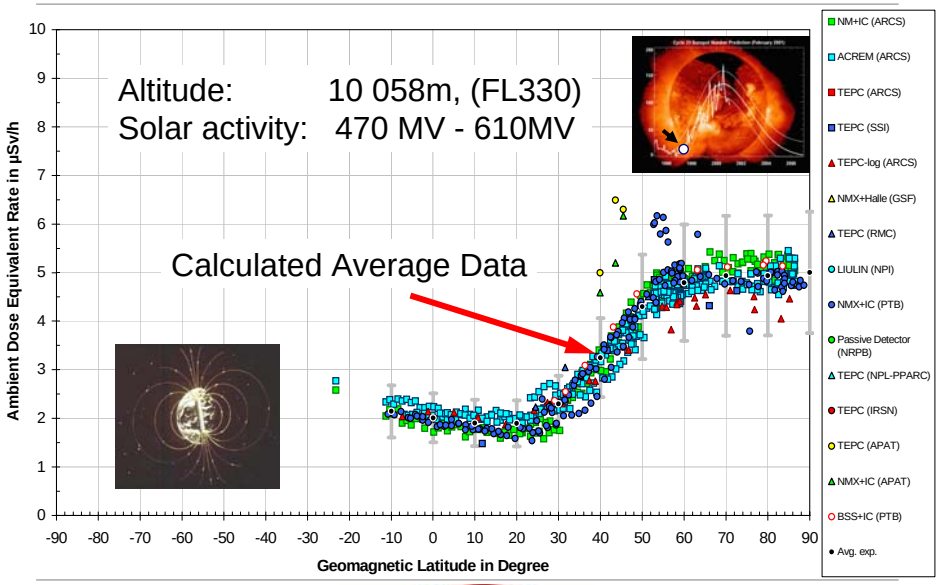

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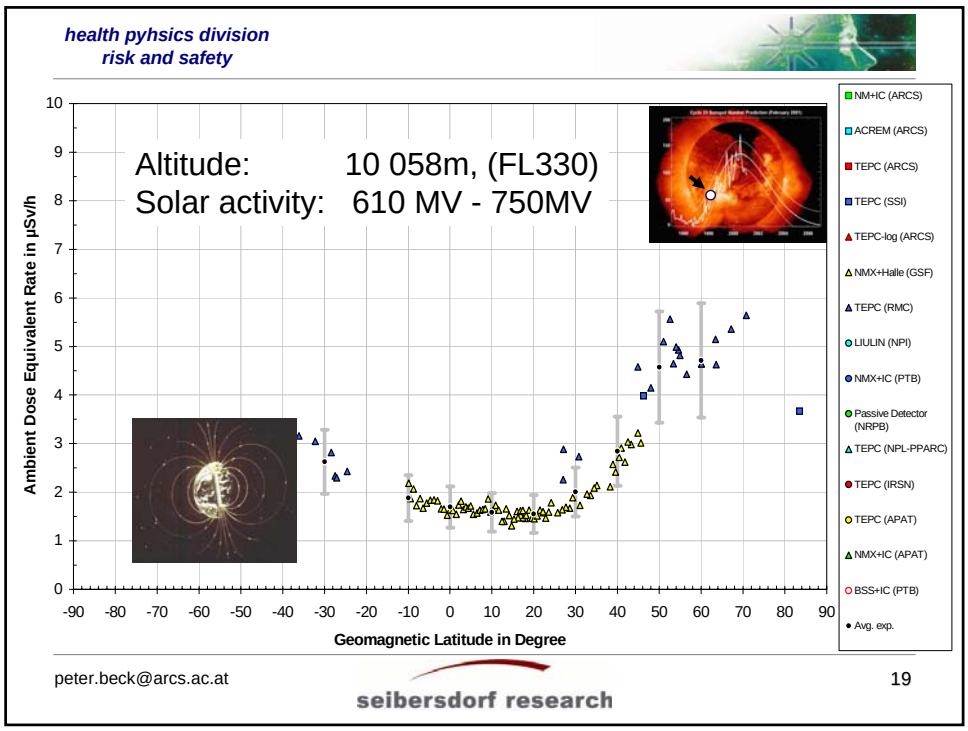

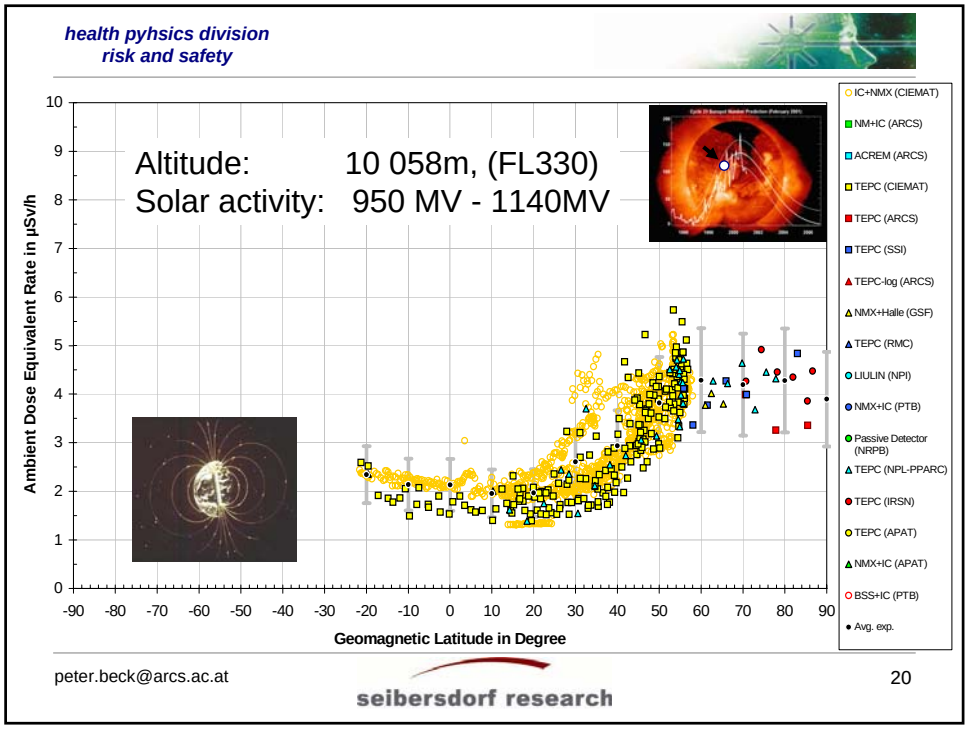

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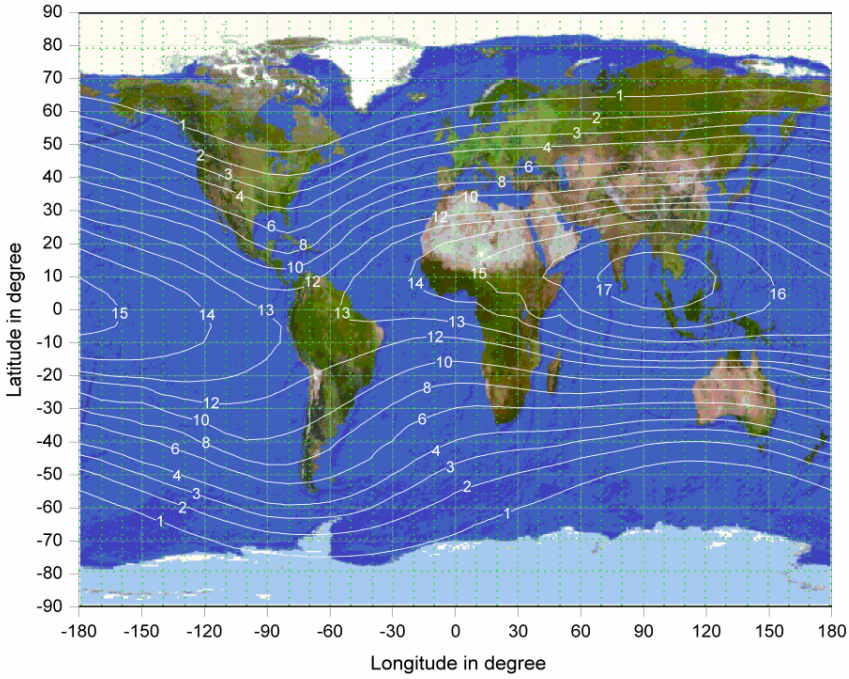

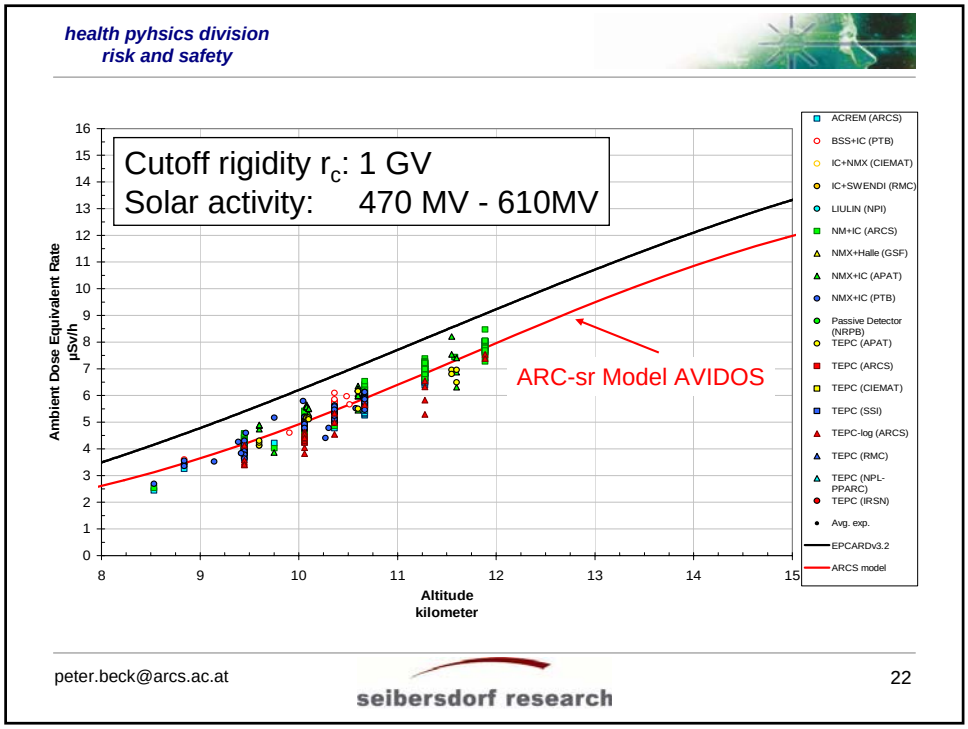

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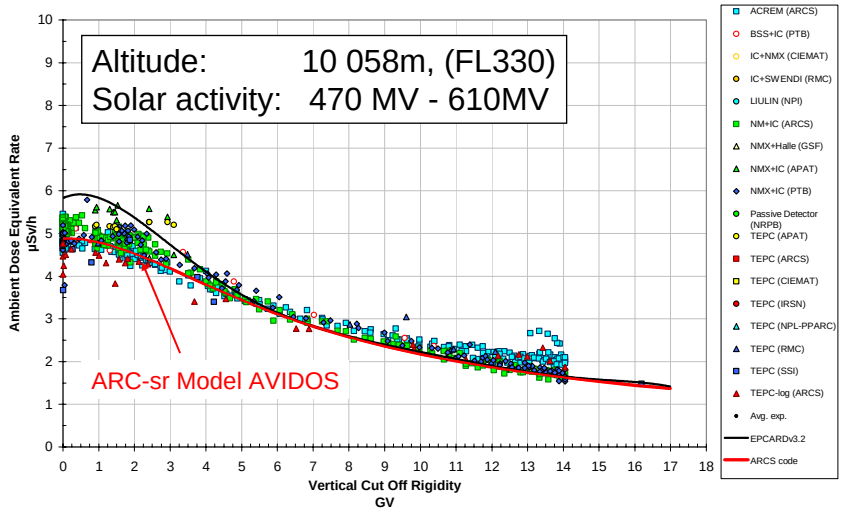

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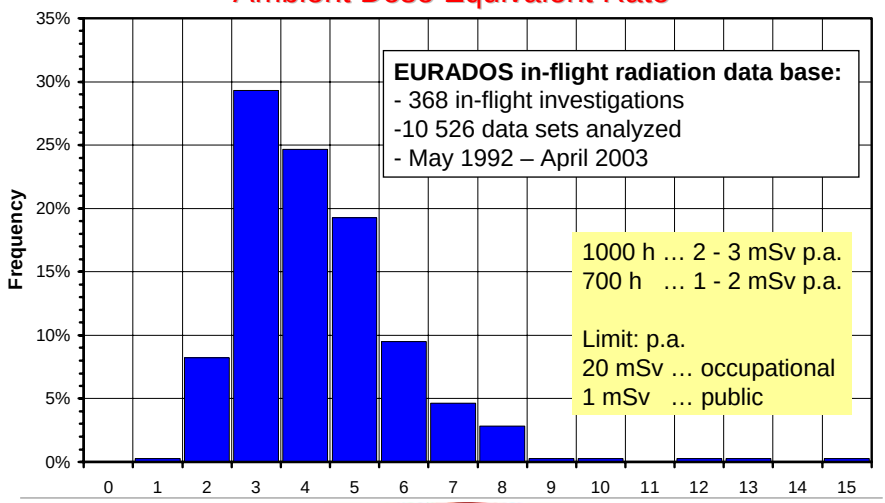
Frequency Distribution of Measured Ambient Dose Equivalent Rate



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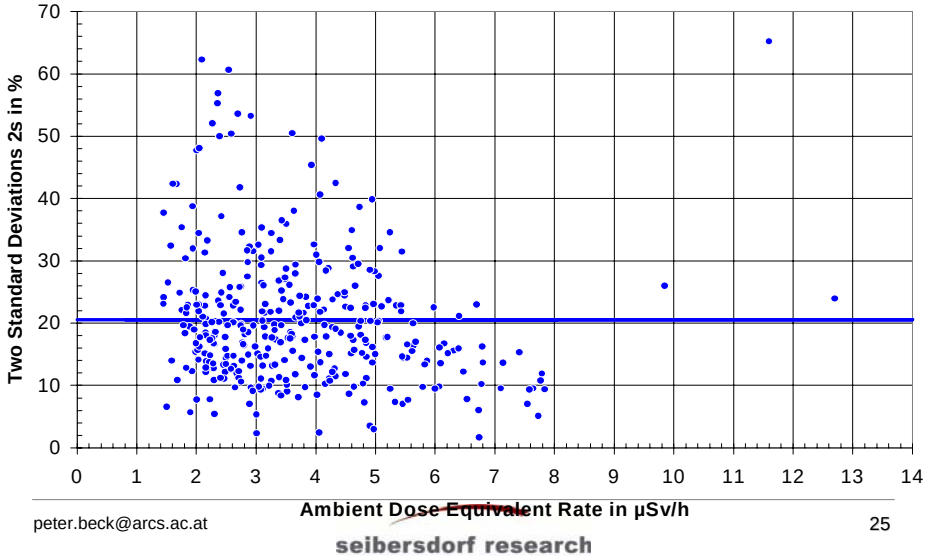
Uncertainty of Mean Ambient Dose Equivalent Rate



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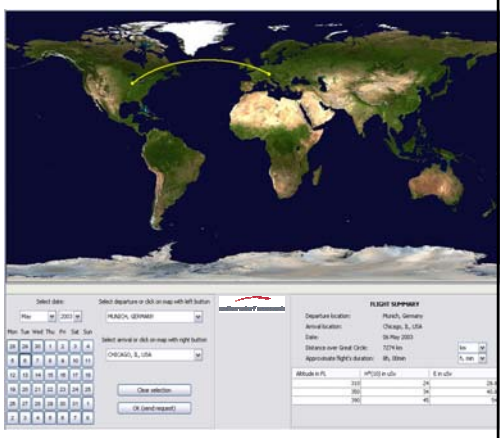
New Aviation Dosimetry Model AVIDOS

- EC-Project ACREM (2000)
  Aircraft Crew Radiation Exporsure Montoring
- EC-Project DOSMAX (2004)
  Aircraft Crew Dosimetrie at Solar Maximum
- EC-EURADOS Report No140 (2005)
  Cosmic Radiation Exposure of Aircraft Crew
- FLUKA 2005
- Updated primary proton spectra
- Effective dose
- Ambient dose equivalent



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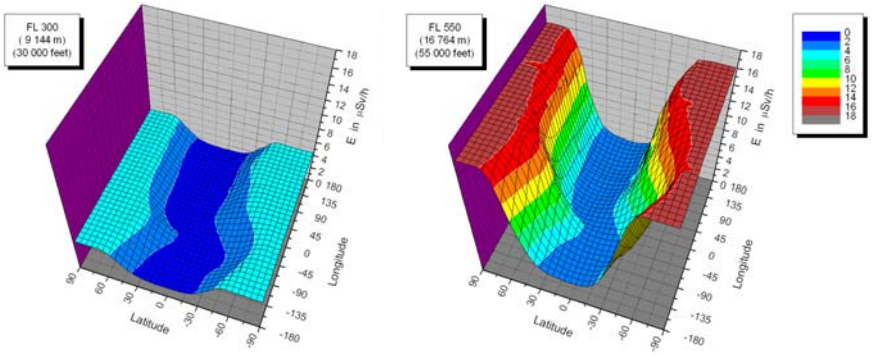
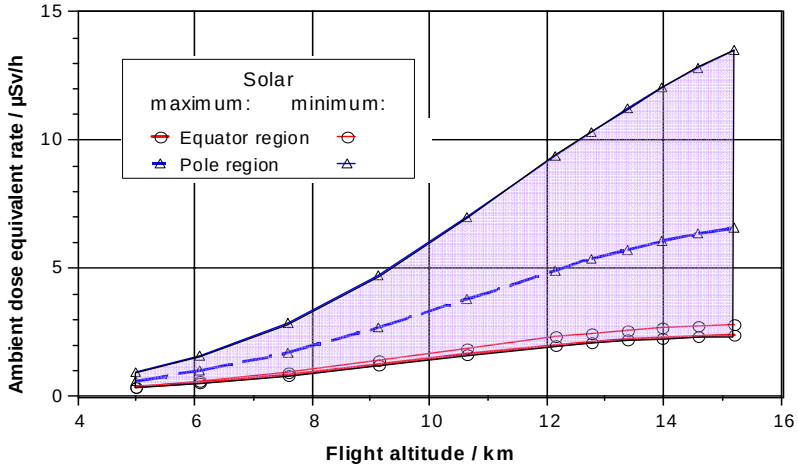
Calculated Effective Dose FL300 und FL550



Radiation Exposure due to Cosmic Radiation ("Quiet Part")



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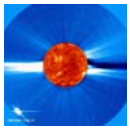
Fix-installation in LH Airbus A340



- Solar Event:

  April 2001 (GLE60)

- Solar Storms:

  October / November 2003

  GLE65, GLE66, GLE67

- Solar Event:

  January 2005

- Literature: ~ 0,05 mSv/h – 1mSv/h

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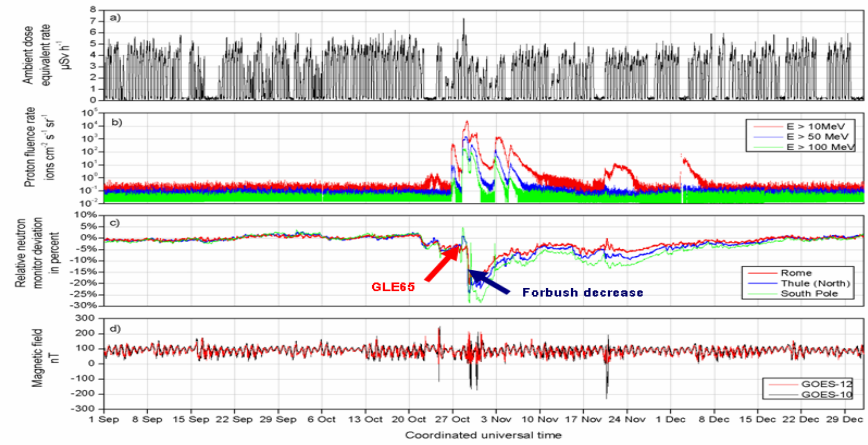
October / November 2003: Solar Storm TEPC measurements



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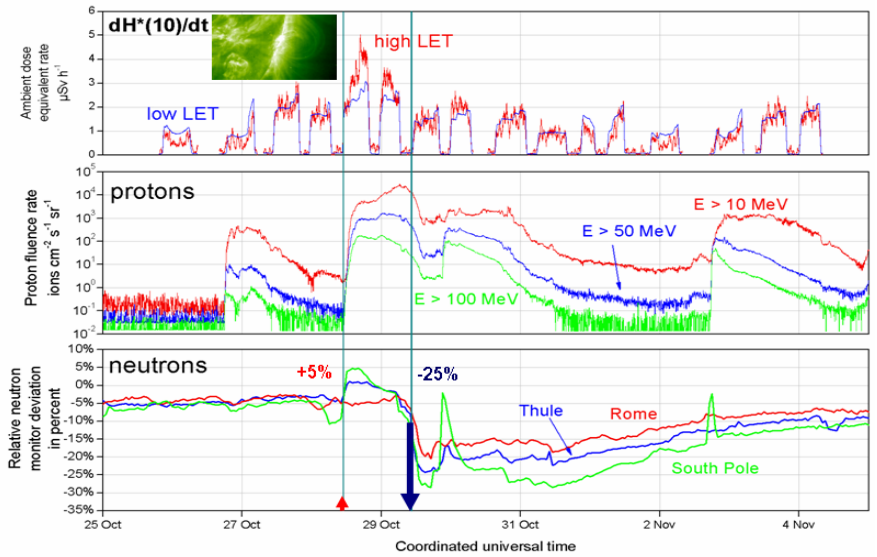

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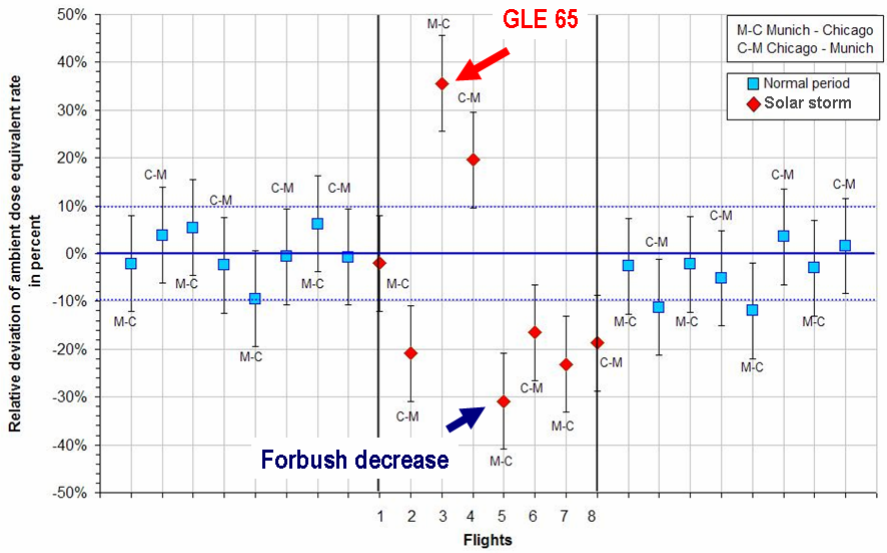

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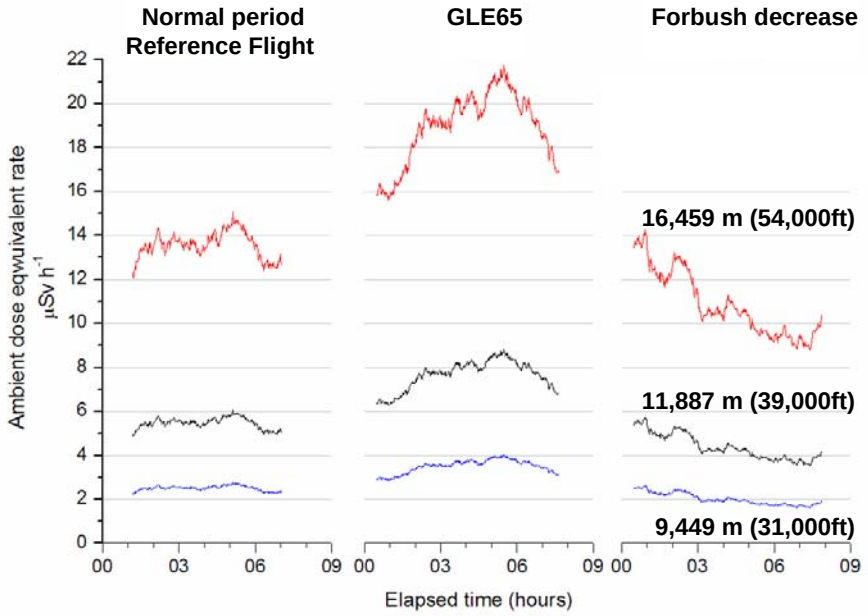

Risk Analysis by Epidemiological Studies

Study	Observed Increase
Finnish and Danish cabin crew cohort study (1995, 1996)	Breast cancer
Canadian pilot cohort study (1996)	Prostate cancer and acute leukaemia
Chromosomal study of Concorde pilots (2000)	Chromosomal aberration
Norwegian pilot cohort study (2000)	Malignant melanoma and non-melanoma skin cancer
German pilots cohort study (2002) (M. Blettner)	No significant increase of cancer

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Further …

- Lang, M., 2004: *Radiation Exposure of Aircraft Crew compared to radiological occupational*
  - *based on Blettner, UNSCEAR, Austrian data*
  - *1,22 mSv (±1,2) p. a … medical occupational*
  - *1,43 mSv (± 0,7) p.a. … aircraft crew*
- Pelliccioni, M., et al., 2004: *Comparison simulation free air / shielding by aircraft and passenger*
  - 15% decreased for E
  - 25% decreased for H*(10)

Conclusion

- Cosmic radiation leads to about 100 times higher exposure compared on Earth
- Typical 5 µSv/h in 10 km altitude
- Some studies show health hazards
- Additional cancer risk small but evident:
  +1% during 35 years aircraft crew activity
- Cosmic radiation exposure has to be assessed in Europe

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Future

- Dose prediction due to ground relevant solar events
  (EC-project CONRAD, WP6 Workplaces of mixed radiation fields)
- ISO-Standard: Dosimetry for exposure to cosmic radiation in civil aircraft (Part 1, 2, 3)
- ICRU / ICRP TG 50: Aircraft Crew Dosimetry (International)
- EURADOS WG5: Aircraft Crew Dosimetry (Europe)
  European Aircraft Crew Dosimetry Expert Network

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Acknowledgements

The cooperation of EURADOS WG5 and support by Aer Lingus, Air Emirates, Air Canada, Air France, Air New Zealand, Alitalia, Austrian Airlines, British Airways, Czech Airlines, Finnair, Iberia, Icelandair, Lufthansa, NASA, Scandinavian Airlines System and VARIG is acknowledged. In some instances, unpublished results have been included of research part-funded by the European Commission, Directorate-General Research, under the auspices of the European Commission RTD Programme: Nuclear Energy (Euratom Framework Programme V, 1998-2002) Contract N° FIGM-CT-2000-00068.

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