

European Research Projects on Aircrew Dosimetry during the last Solar Cycle – an Overview

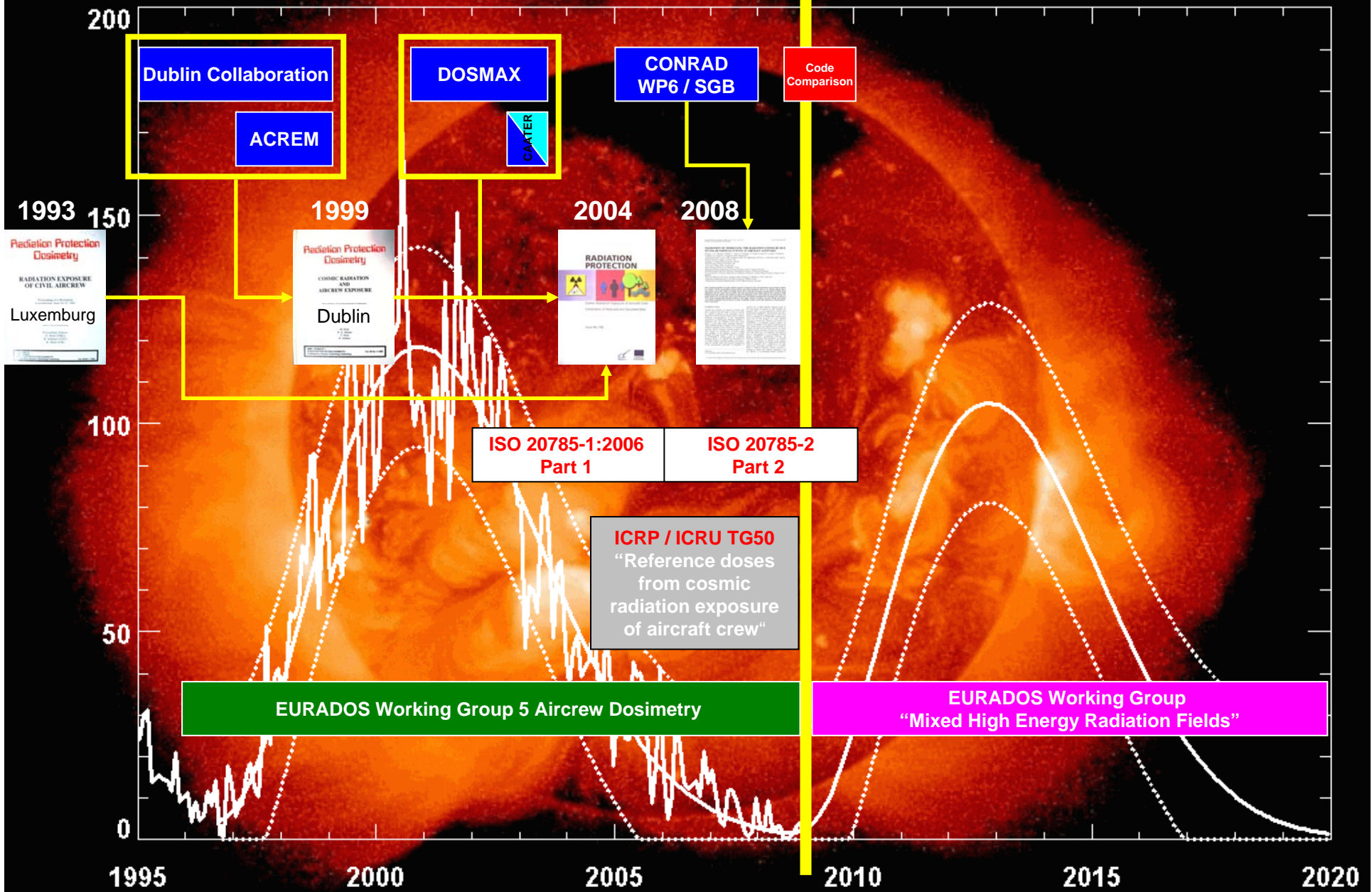
EURADOS Workshop “Cosmic Radiation and Aircrew Exposure”

EURADOS Annual Meeting, 29 January 2009, PTB Braunschweig
Dr. Peter Beck, Head ARC / HNA / Radiation Research

Content

- Aircrew dosimetry projects
- Major achievements
- Conclusions
- Future challenge

Cycle 23-24 Sunspot Number Prediction (January 2009)



Dublin Collaboration - Study of Radiation Fields and Dosimetry at Aviation Altitudes

- **EC Project:** No.F14P-CT950011a
- **Coordinator:** D. O'Sullivan (DIAS, Dublin, Ireland)
- **5 years:** 1995 to 1999

- **Project partners & subcontractors:**
 - R.E. Grillmaier*, (USSAR), Germany
 - L. Lindborg*, (SSI), Stockholm, Sweden
 - L. Tommasino*, (APAT), Rome, Italy
 - H. Shraube*, (GSF), Neuherberg, Germany
 - D.T. Bartlett* (HPA), Chilton Didcot, UK

Table 1. Basic physical characteristics of the devices used by the participating laboratories.

Laboratory	Detector	Radiation detected	Approximate energy range
<i>Dublin Collaboration Instrument Array</i>			
USAAR	TEPC	Low/High LET	$1 \leq L \leq 1000 \text{ keV} \cdot \mu\text{m}^{-1}$
SSI	TEPC (variance technique)	Low/High LET	$1 \leq L \leq 1000 \text{ keV} \cdot \mu\text{m}^{-1}$
ANPA	Extended rem meter	Neutrons	1 MeV - 10 GeV
GSF	Multisphere spectrometer	Neutrons	1 MeV - 10 GeV
NRPB	TLD	Low and High LET radiation	All energies
	PADC	Neutrons	All energies
DIAS	CR-39	Neutron interaction products	$\text{LET} \geq 5 \text{ keV} \cdot \mu\text{m}^{-1}$
	CR-39	Particles $Z \geq 2$	$E \geq 7 \text{ MeV/N}$
ANPA	TLD	Low LET radiation	
	Bubble detectors	Fast neutrons	0.5 to 20 MeV
	Bi-Mylar	Neutrons and protons	$\geq 50 \text{ MeV}$
	ANPA Stack	Fast neutrons	0.5 to 20 MeV

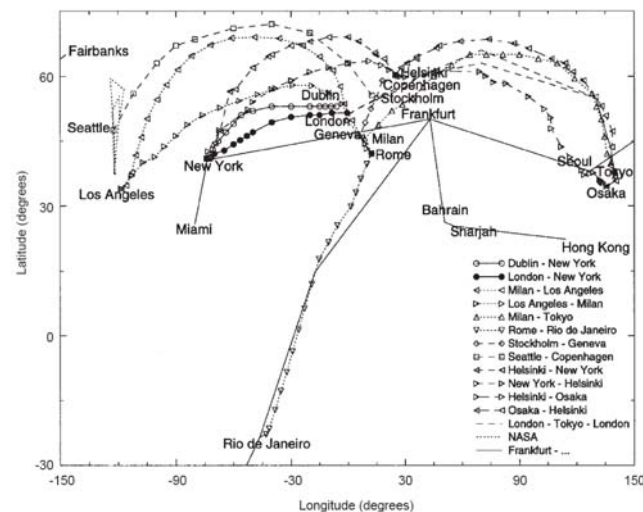


Figure 1. Flight routes investigated in the present European Commission Programme.

Dublin Collaboration - Study of Radiation Fields and Dosimetry at Aviation Altitudes

Unique: Investigations for $Z > 1$ with stacks of solid state nuclear detectors

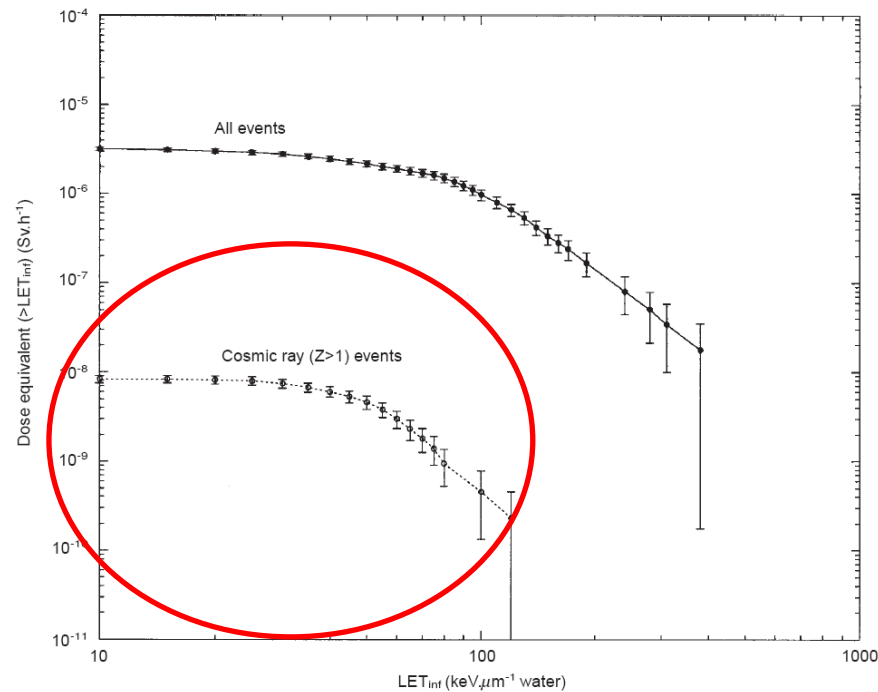
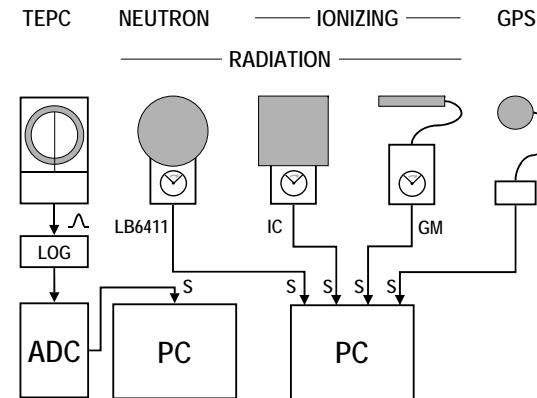


Figure 2. A comparison of the contribution of $Z > 1$ cosmic ray primary and secondary nuclei to dose equivalent with the total dose equivalent from all events.

ACREM – Aircraft Crew Radiation Exposure Monitoring

- **EC Project:** No. F14P-CT960047
- **Coordinator:** P. Beck
(ARC Seibersdorf, Austria)
- **3 years:** 1997 to 1999
- **Project partners & subcontractors:**
 - U. Schrewe* (PTB), Braunschweig, Germany
 - G. Walle* (DLH), Frankfurt, Germany
 - K. O'Brien* (NAU), USA
 - E. Felsberger* (TU-Graz), Austria

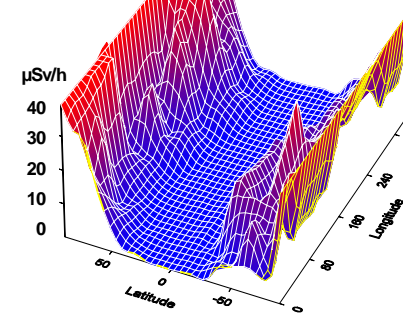
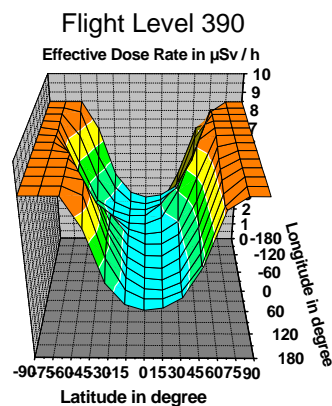
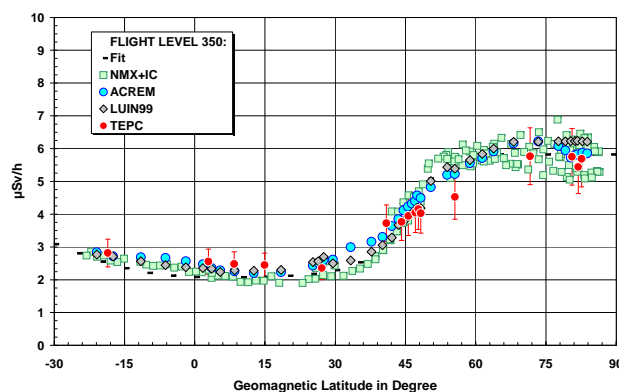
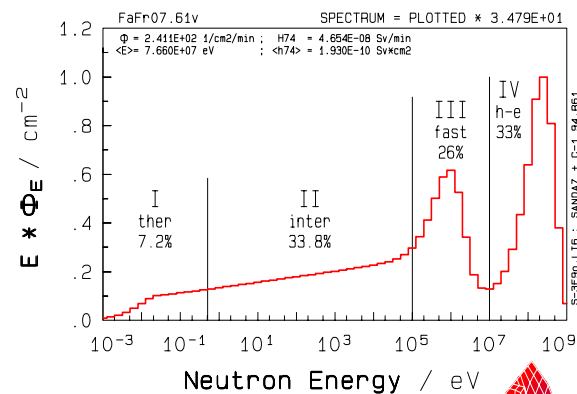
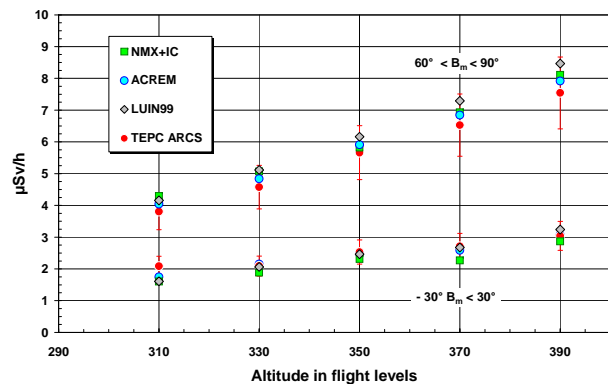


ACREM – Aircraft Crew Radiation Exposure Monitoring

No	Destination	Stages	ICAO Code	Date	SP in MV
1	Seoul	Frankfurt - Fairbanks	FRA-FAI	22. 5.97	474
		Fairbanks - Seoul	FAI-SEL	24. 5.97	474
		Seoul - Fairbanks	SEL-FAI	27. 5.97	474
		Fairbanks - Frankfurt	FAI-FRA	28. 5.97	474
2	Fairbanks	Frankfurt - Fairbanks	FRA-FAI	29. 9.97	480
		Fairbanks - Frankfurt	FAI-FRA	30. 9.97	480
3	New York	Frankfurt - New York	FRA-JFK	27.10.97	496
		New York - Miami	JFK-MIA	29.10.97	496
		Miami - New York	MIA-JFK	30.10.97	496
		New York -Frankfurt	JFK-FRA	31.10.97	496
4	Buenos Aires	Frankfurt - Dakar	FRA-DKR	11. 2.98	493
		Dakar - Sao Paulo	DKR-VCP	11. 2.98	493
		Sao Paulo - Buenos Aires	VCP-EZE	14. 2.98	493
		Buenos Aires - Sao Paulo	EZE-VCP	14. 2.98	493
		Sao Paulo - Rio de Janeiro	VCP-GIG	16. 2.98	493
		Rio de Janeiro - Dakar	GIG-DKR	16. 2.98	493
5	Hong Kong	Dakar - Frankfurt	DKR-FRA	17. 2.98	493
		Frankfurt - Bahrein	FRA-BAH	22. 3.98	496
		Bahrein - Sharjah	BAH-SHJ	23. 3.98	496
		Sharjah Hong Kong	SHJ-HKG	23. 3.98	496
		Hong Kong - Sharjah	HKG-SHJ	26. 3.98	496
6	New York	Sharjah - Frankfurt	SHJ-FRA	27. 3.98	496
		Frankfurt - New York	FRA-JFK	24. 4.98	562
7	Seoul	New York - Frankfurt	JFK-FRA	26. 4.98	562
		Frankfurt - Fairbanks	FRA-FAI	14. 6.98	640
8	Chicago	Fairbanks - Seoul	FAI-SEL	16. 6.98	640
		Seoul - Fairbanks	SEL-FAI	18. 6.98	640
		Fairbanks - Frankfurt	FAI-FRA	18. 6.98	640
		Frankfurt - Chicago	FRA-ORD	2.10.98	535
9	Buenos Aires	Chicago - Frankfurt	ORD-FRA	4.10.98	535
		Frankfurt - Dakar	FRA-DKR	10.12.98	581
10	Fairbanks	Dakar - Sao Paulo	DKR-VCP	10.12.98	581
		Sao Paulo - Buenos Aires	VCP-EZE	14.12.98	581
		Buenos Aires - Montevideo	EZE-MVD	14.12.98	581
		Montevideo - Sao Paulo	MVD-VCP	14.12.98	581
		Sao Paulo - Dakar	VCP-DKR	15.12.98	581
		Dakar - Frankfurt	DKR-FRA	15.12.98	581
10	Fairbanks	Frankfurt - Fairbanks	FRA-FAI	18. 2.99	650
		Fairbanks - Frankfurt	FAI-FRA	22. 2.99	650



ACREM – Aircraft Crew Radiation Exposure Monitoring



GLE42, 29 to 30 September, 1989

DOSMAX - Dosimetry of aircrew exposure to radiation during solar maximum

- **EC Project:** No. FIGM-CT-2000-00068
- **Coordinator:** D. O'Sullivan (DIAS, Dublin, Ireland)
- **4 years:** July 2000 to Sep 2004

- **Project partners & subcontractors:**
 - D.T. Bartlett* (HPA), Chilton Didcot, UK
 - P. Beck*, (ARC Seibersdorf), Seibersdorf, Austria
 - J.-F. Bottollier-Depois*, (IRSN), Paris, France
 - L. Lindborg*, (SSI), Stockholm, Sweden
 - F. Wissmann*, (PTB), Braunschweig, Germany
 - L. Tommasino*, (APAT), Rome, Italy
 - M. Pelliccioni*, (INFN), Frascati, Italy
 - H. Roos*, Ludwig-Maximilians-Universität München, Germany
 - H. Schraube*, (GSF), Neuherberg, Germany
 - M. Silari*, (CERN), Geneva, Switzerland
 - F. Spurny*, Academy of Sciences, Prague, Czech

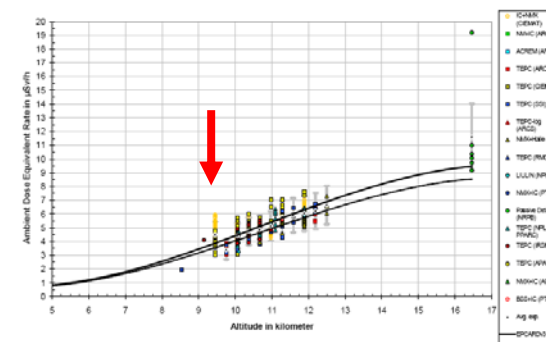
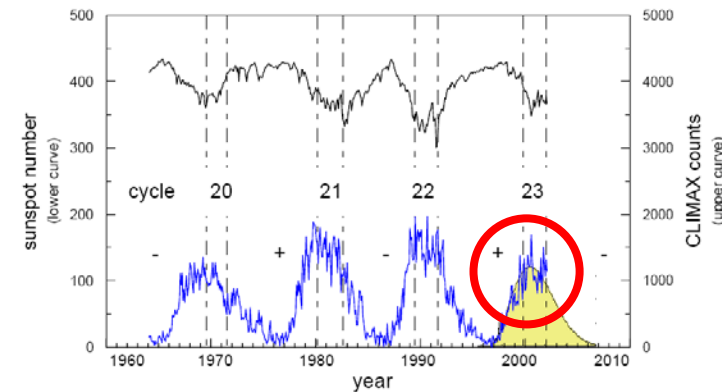


Figure III. 62 Ambient dose equivalent rate $dH^*(10)/dt$ vs. standard barometric altitude between May 1992 and May 2003 for vertical cut off rigidity $r_c \leq 2$ GV and solar deceleration potential in the range of 950 MV - 1140 MV.

DOSMAX measurements during Solar Storms

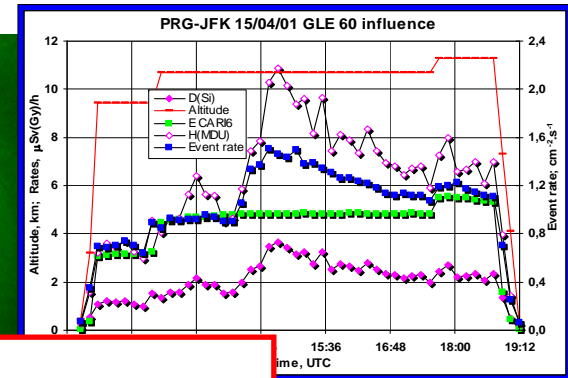
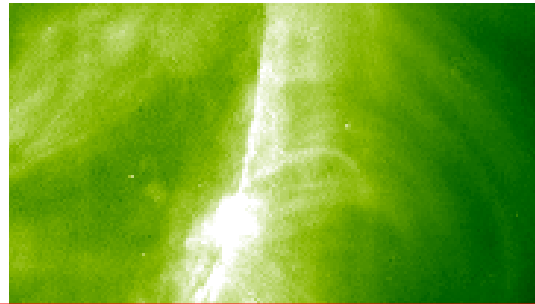
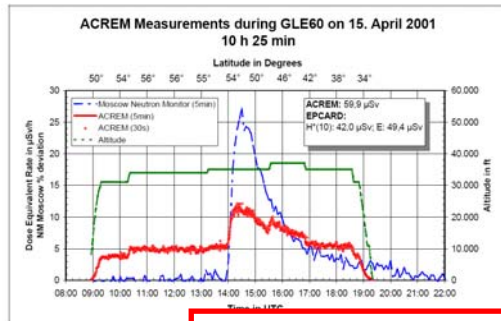


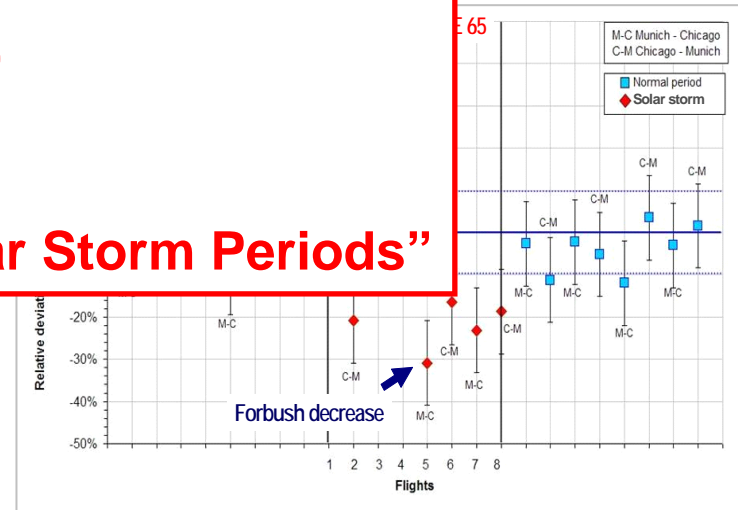
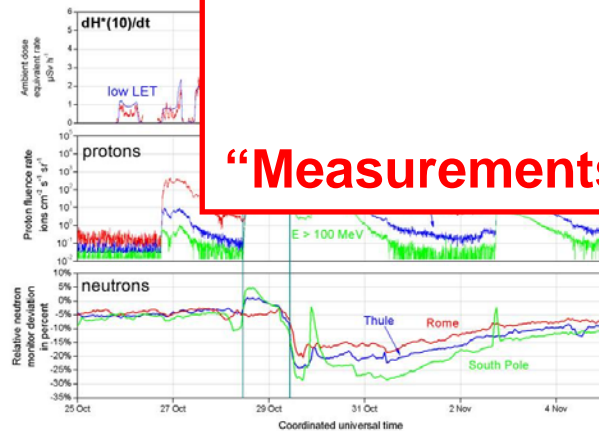
Figure 4.6. Measurement results during GLE60 on 15. April 2001. Same time as the neutron monitor (blue) at ground level.

Detailed talk tomorrow!

9:30 – 9:50

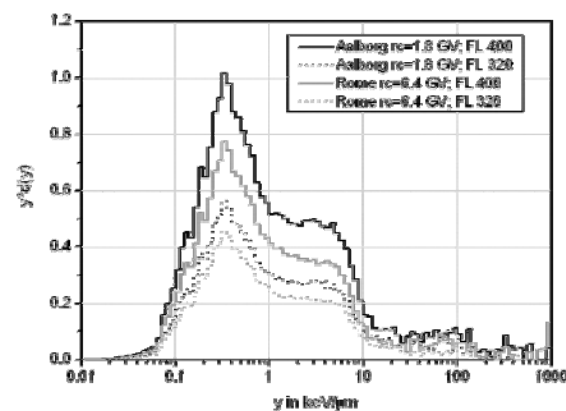
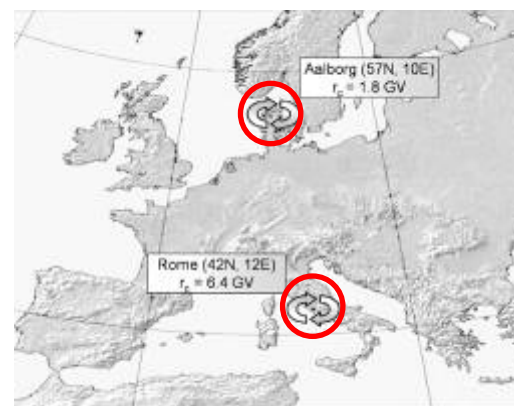
P. Beck

“Measurements during Solar Storm Periods”



CAATER - Coordinated Access to Aircraft for Transnational Environmental Research Project: “Comparison of precise ionising radiation dose measurements on board aircraft”

- No: EAE03-A-14707
- **Coordinator: L. Lindborg**
(SSI, Sweden)
- **March, 2000**
- **Project partners:**
- *P. Beck*, (ARC Seibersdorf), Seibersdorf, Austria
- *J.-F. Bottollier-Depois*, (IRSN), Paris, France
- *F. Wissmann*, (PTB), Braunschweig, Germany
- *H. Roos*, Ludwig-Maximilians-Universität München, Germany
- *F. Spurny*, Academy of Sciences, Prague, Czech

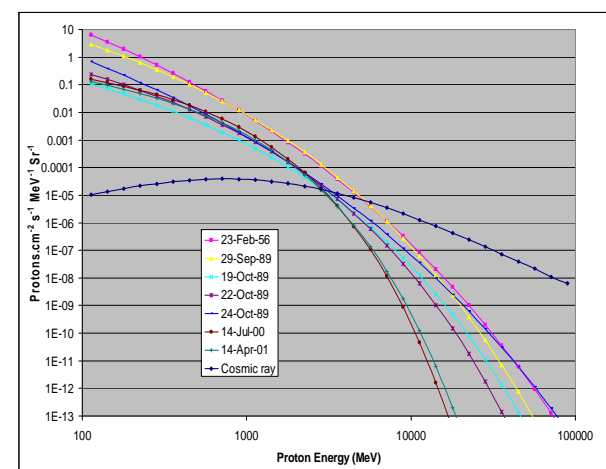
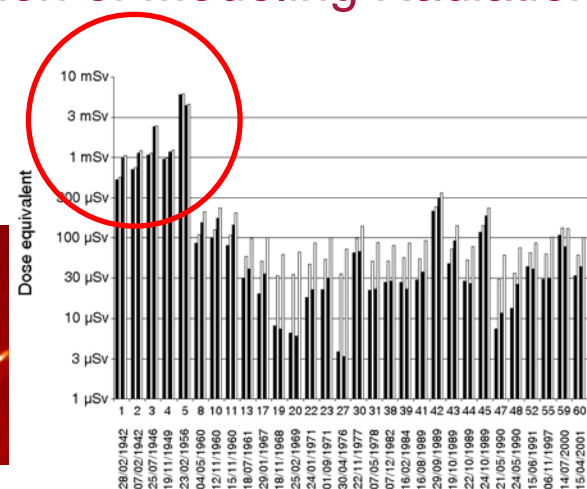
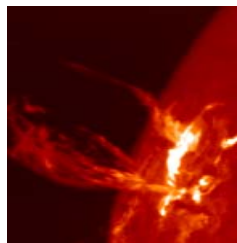


**TEPC measurements
agree within < 10%**

CONRAD / WP6 / Sub Group B - Validation of Modeling Radiation Exposure due to Solar Particle Events

- **WP6 / SGB Coordinator: P. Beck**
(ARC, Seibersdorf, Austria)
3 years: Jan 2005 to Dec 2007

- **Members:**
 - L. Hager (HPA), UK
 - P. Bilski, (INP), Poland
 - C. Dyer (QinetiQ), UK
 - E. Flückiger (University of Bern), Switzerland
 - N. Fuller (Paris-Meudon Observatoire), France
 - P. Lantos (Paris-Meudon Observatoire), France
 - G. Reitz (DLR), Germany
 - W. Rühm (Helmholz Zentrum München), Germany
 - F. Spurny, Academy of Sciences, Prague Czech
 - G. Taylor, NPL, UK
 - F. Trompier, IRSN, France
 - F. Wissmann, PTB, Braunschweig, Germany

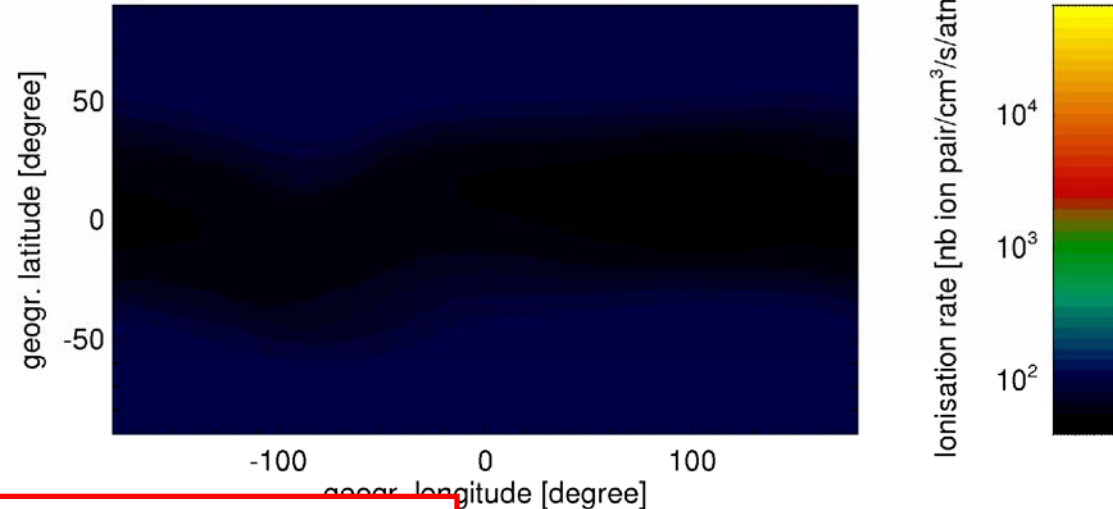


**Currently available SEP models
can disagree with each other in
the order of one magnitude!**

Ionisation at 10,000 m Altitude

GLE 69
20 Januar 2005

Atmospheric ionisation at 250 g/cm², 20th January 2005

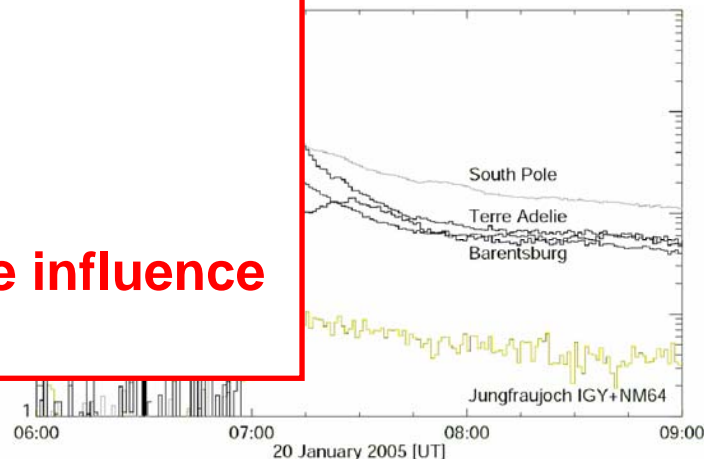


Detailed talk tomorrow!

9:00 – 9:30

Prof. E. Flückiger

**“Solar particle events and the influence
on aircrew doses”**



Comparison of code estimating radiation exposure due to Galactic Cosmic Radiation (GCR)



Detailed talk tomorrow!

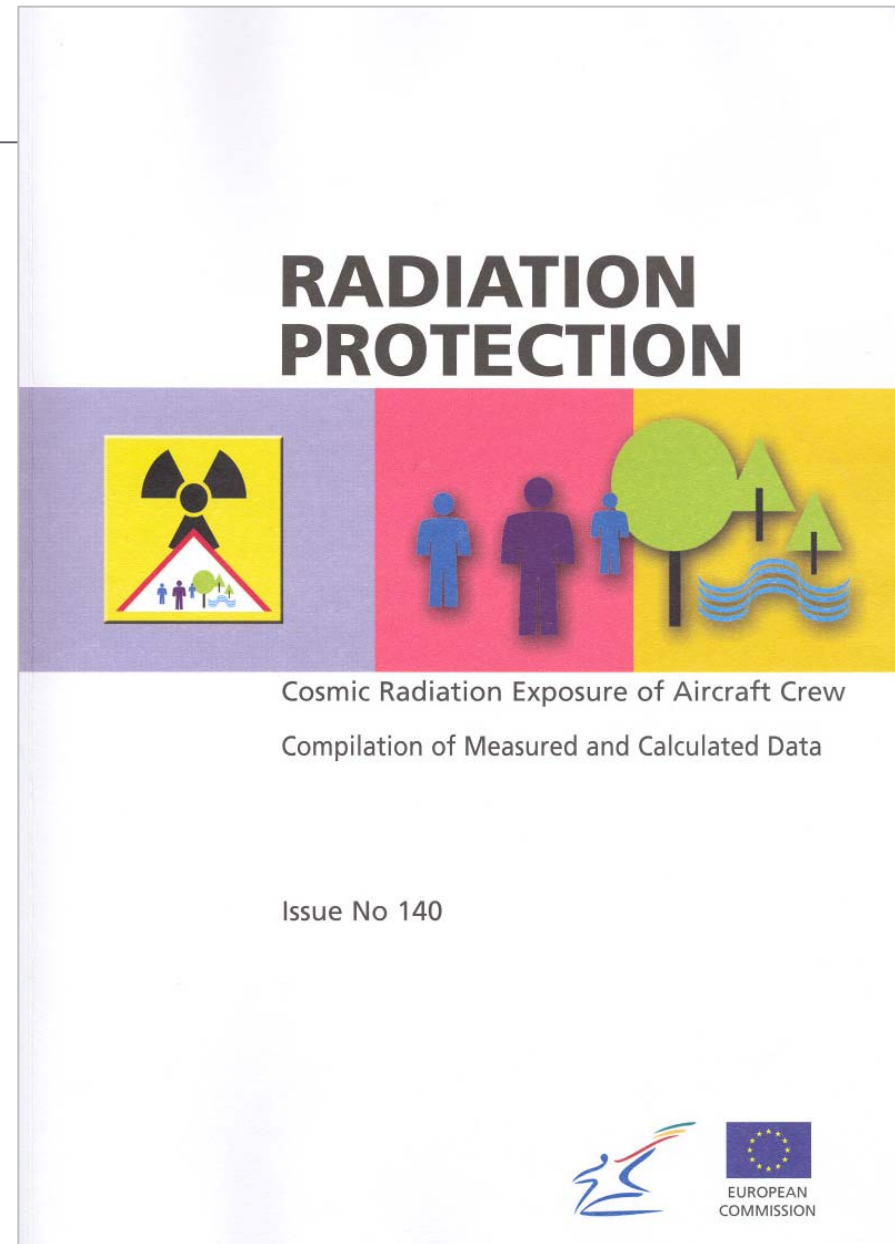
12:00 - 12:20

J.F. Bottollier Depois

“Code Comparison of EURADOS WG5”

Key Reports, ISO Standards

1. *Radiation Exposure of Civil Aircrew*, **RPD**, Vol.48 No.1, 1993
2. *Exposure of Air Crew to Cosmic Radiation*, **EC**, Radiation Protection Issue No. 85, 1996
3. *Cosmic Radiation and Aircrew Exposure*, **RPD**, Vol.86 No.4, 1999
4. ***Cosmic Radiation Exposure of Aircraft Crew – Compilation of Measured and Calculated Data***, **EC** Issue No.140, 2004
 - **ISO** Standard 20785-1:2006, Part 1
 - **ISO** Standard 20785-2, Part 2 (under preparation)



EURADOS Working Group 5 on Aircraft Crew Exposure

D.T. Bartlett¹, P. Beck², P. Bilski³, J.-F. Bottollier-Depois⁴, L. Lindborg⁵ (Chairman from 2003), H. Schraube⁶, F. Spurny⁷ and F. Wissmann⁸, E. Felsberger⁹ (resigned in 2002), W. Heinrich¹⁰, B. Lewis¹¹, D. O'Sullivan¹², G. Reitz¹³, U. Schrewe¹⁴ (Chairman 2000 to 2002), and L. Tommasino¹⁵, G. Dietze⁸ for Article 31, I. McAulay¹⁶ for Article 31, J. Siedenburg¹⁷ (2004) and A. Ruge (2000–2003) for JAA, K. Schnuer¹⁸ for EC and K. Ulbak¹⁹ 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⁽⁶⁾ and their colleagues.

- (1) National Radiological Protection Board (NRPB), Chilton Didcot, UK
- (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
- (14) Fachhochschule, Hannover, Germany
- (15) National Agency for Environmental Protection and Technical Services (APAT), Rome, Italy
- (16) Trinity College, Dublin, Ireland
- (17) Central Joint Aviation Authority (JAA), Hoofddorp, 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
- (22) National Physical Laboratory, Teddington, U.K.
- (23) Fachrichtung Biophysik, Universität des Saarlandes, Homburg/Saar, Germany
- (24) Civil Aerospace Medical Institute, Federal Aviation Administration, Oklahoma City, USA
- (25) Northern Arizona University, Flagstaff, Arizona, USA
- (26) INFN, Laboratori Nazionali di Frascati, Frascati, Italy

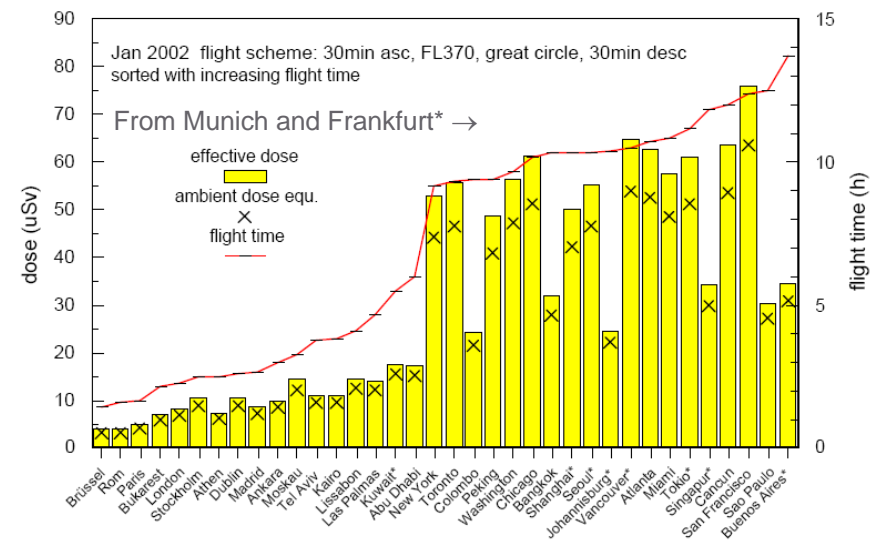
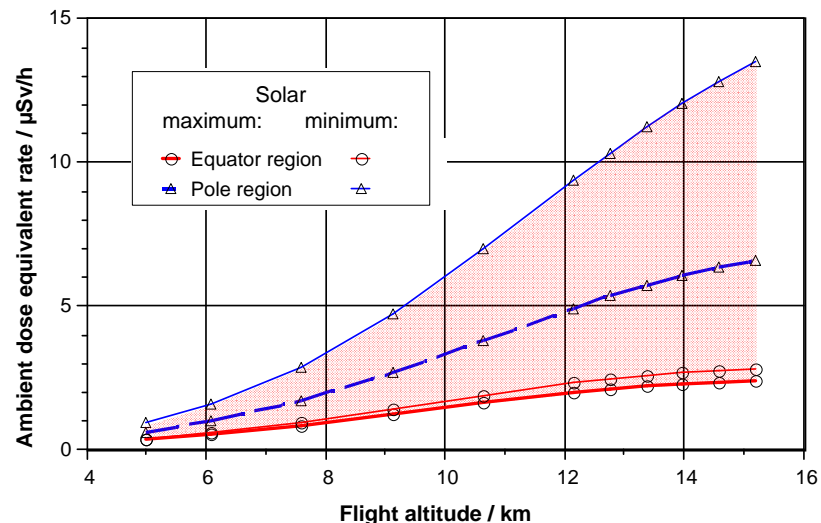


Table III.2: List of dose assessment methods during in-flight investigations

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 (ARCS)	TEPC (HAWK) [BEC03], [BEC04]	30 - 60 min
TEPC (RMC)	TEPC (FAR WEST detector) [GRE00] [LEW01]	25 min
TEPC (SSI)	TEPC instruments based on the variance method [KYL01]	30 - 60 min
TEPC (CIEMAT)	TEPC (HAWK) [SAE02] [ROM04] [SAE04a] [SAE04b]	25 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-dosimeter developed originally for space (MDU-Liulin) [SPU03]	30 min
Track Detector (NRPB)	Box with 36 PADC and 30 TL dosimeters [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

Agreement of measurements within 20% (2s)

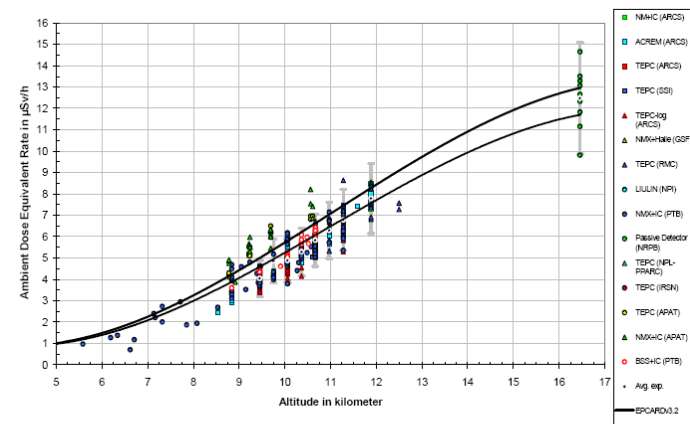
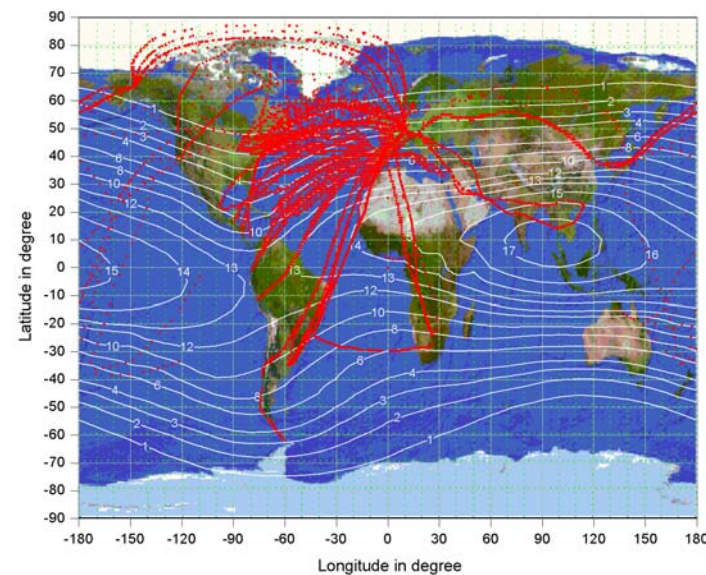
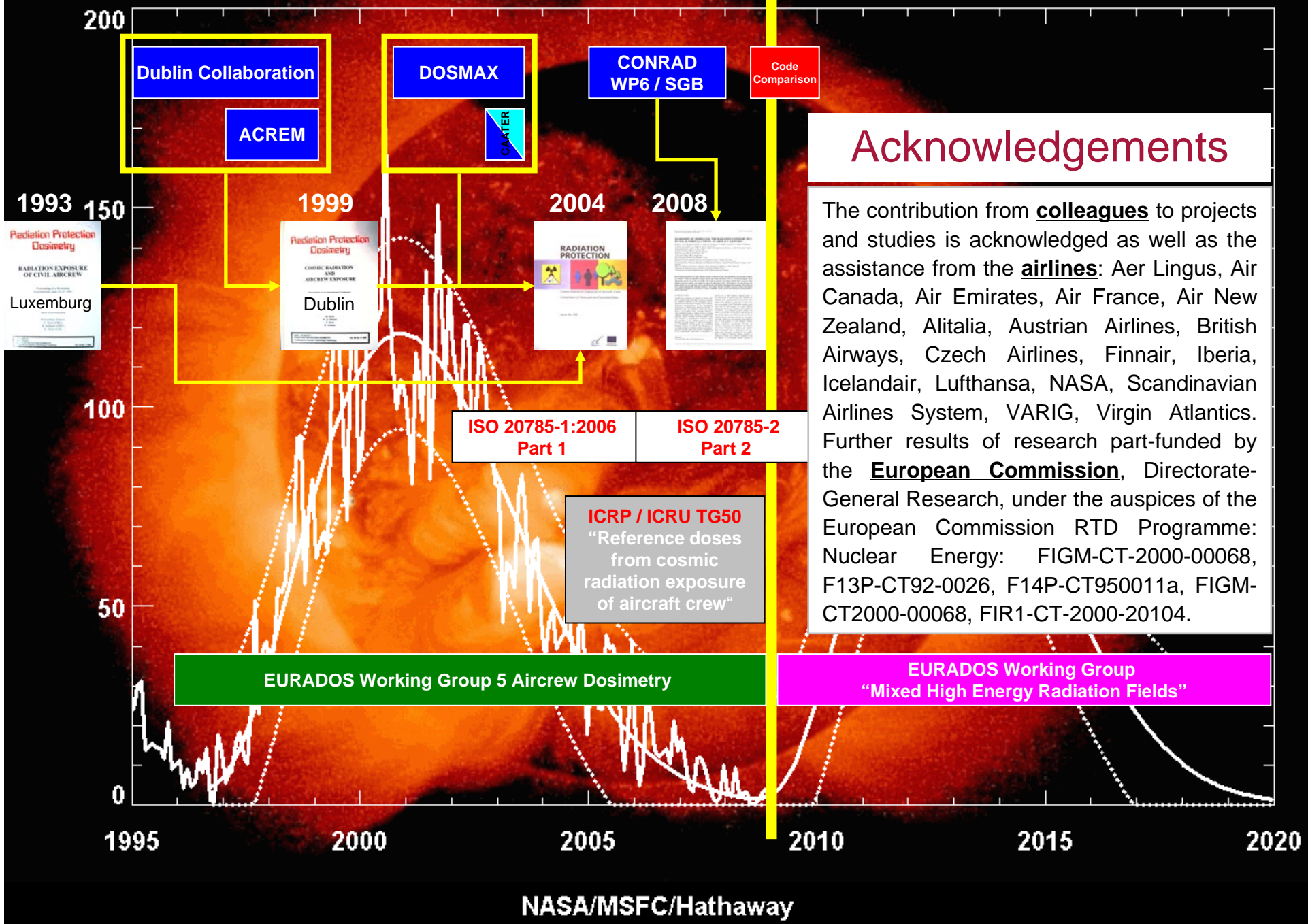


Figure III. 60 Ambient dose equivalent rate $dH^*(10)/dt$ vs. standard barometric altitude between May 1992 and May 2003 for vertical cut off rigidity $r_c \leq 2$ GV and solar declination potential in the range of 470 MV - 610 MV.

Summary, Conclusion and Future

- **4 EC research projects in 12 years (1995 – 2007)**
- High precision in-flight **TEPC comparison (CAATER)**
- **Experimental** assessment of radiation exposure from **Solar Particles Events (SPE)**
- **Validation study of SPE** exposure calculations
- **Key comparison** of codes estimating radiation exposure due to **GCR**
- **4** comprehensive scientific reports
- **ISO standard** “Dosimetry for exposures to cosmic radiation in civilian aircraft”
- **Agreement of measurements and calculations within 30% (GCR)**
- **Continue** validation of **SPE radiation** exposure calculation models
- **Improve** expertise in aircrew dosimetry!
- **Continuous measurements** of cosmic radiation (ground level, aircraft)

Cycle 23-24 Sunspot Number Prediction (January 2009)



Acknowledgements

The contribution from **colleagues** to projects and studies is acknowledged as well as the assistance from the **airlines**: Aer Lingus, Air Canada, Air Emirates, Air France, Air New Zealand, Alitalia, Austrian Airlines, British Airways, Czech Airlines, Finnair, Iberia, Icelandair, Lufthansa, NASA, Scandinavian Airlines System, VARIG, Virgin Atlantic. Further results of research part-funded by the **European Commission**, Directorate-General Research, under the auspices of the European Commission RTD Programme: Nuclear Energy: FIGM-CT-2000-00068, F13P-CT92-0026, F14P-CT950011a, FIGM-CT2000-00068, FIR1-CT-2000-20104.