65TH INTERNATIONAL CONGRESS OF AVIATION AND SPACE MEDICINE
Rome, 10-14 September 2017

SOME CONSIDERATIONS ON AIRCREW EXPOSURE TO COSMIC RAYS

QUELQUES CONSIDÉRATIONS SUR L'EXPOSITION DES L'AÉRIENNE EQUIPAGE AUX RAYONS COSMIQUES

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Gemelli Fondazione Policlinico Universitario A. Gemelli Università Cattolica del Sacro Cuore

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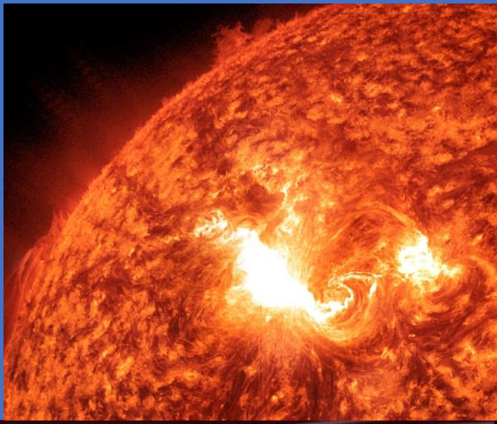
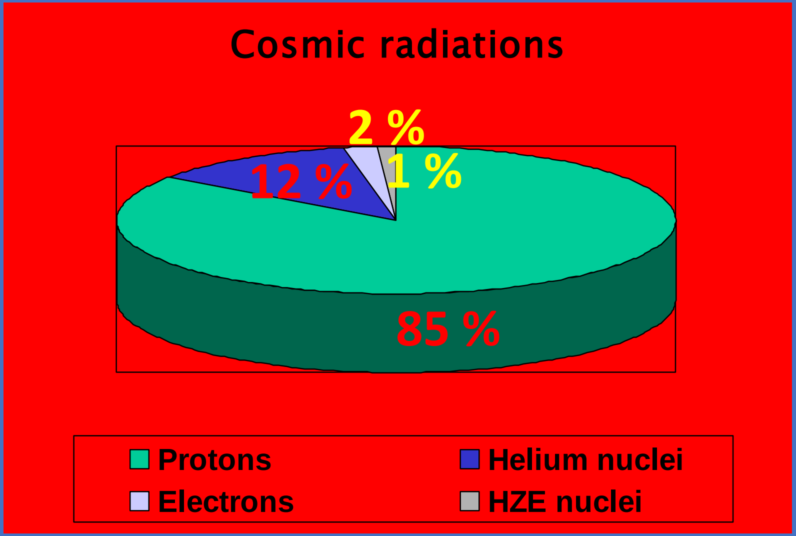
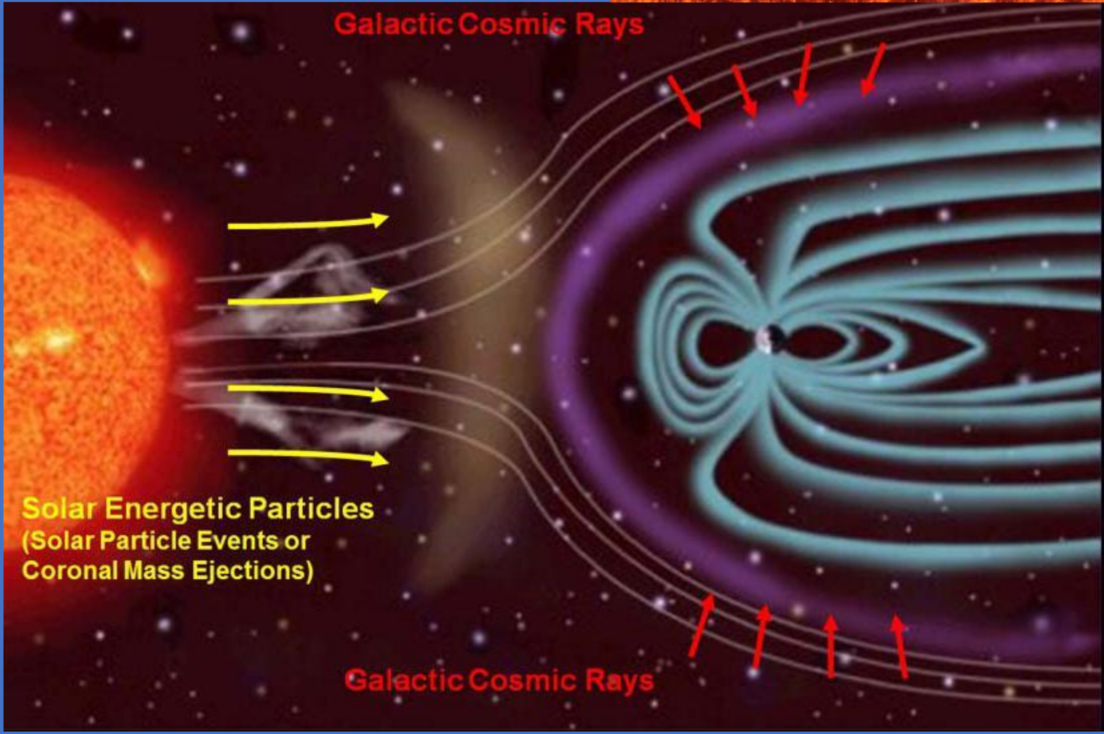
Cosmic radiations



Cosmic radiations are originated by stars, galactics and sun activities due to high energy astrophysical processes.

1) Galactic/extragalactic radiations
2) Solar Energetic Particles: by solar wind and solar flares





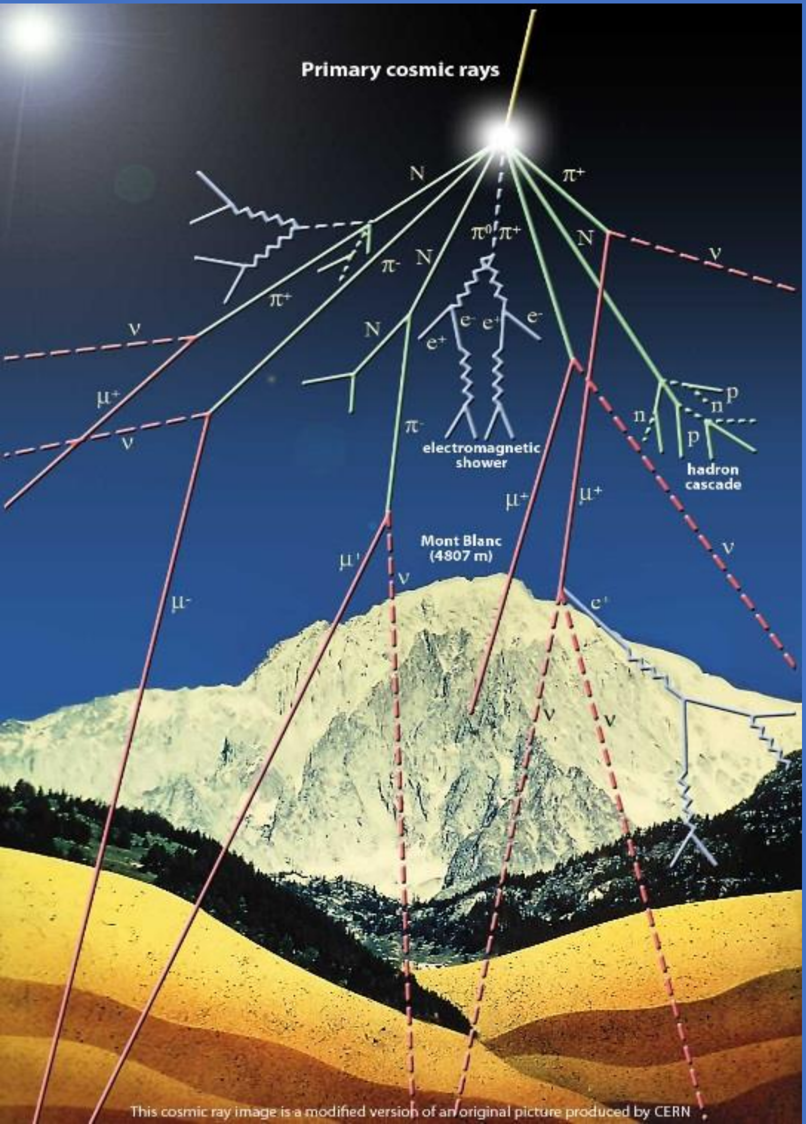
Credit http://photojournal.jpl.nasa.gov/jpeg/PIA16938.jpg

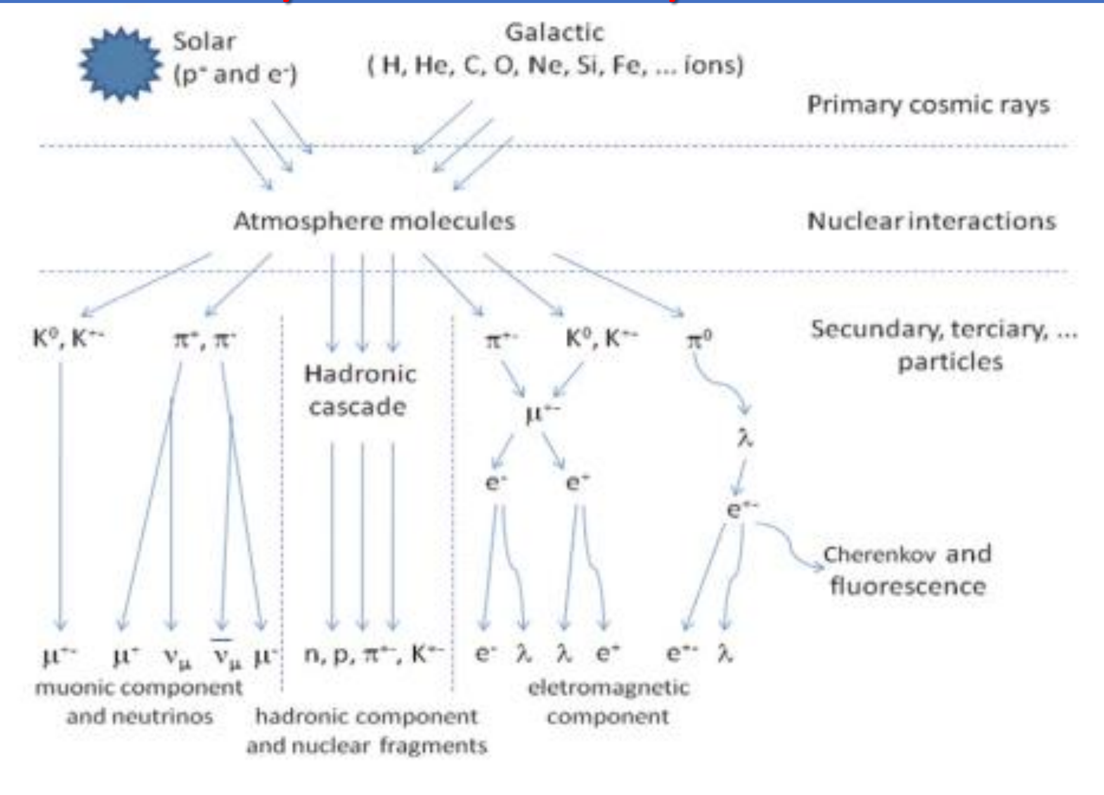
Interaction with the atmosphere

The interaction with the outer atmosphere creates secondary and terciary cosmic radiations made of: Hadrons

Neutrons Electrons Leptons

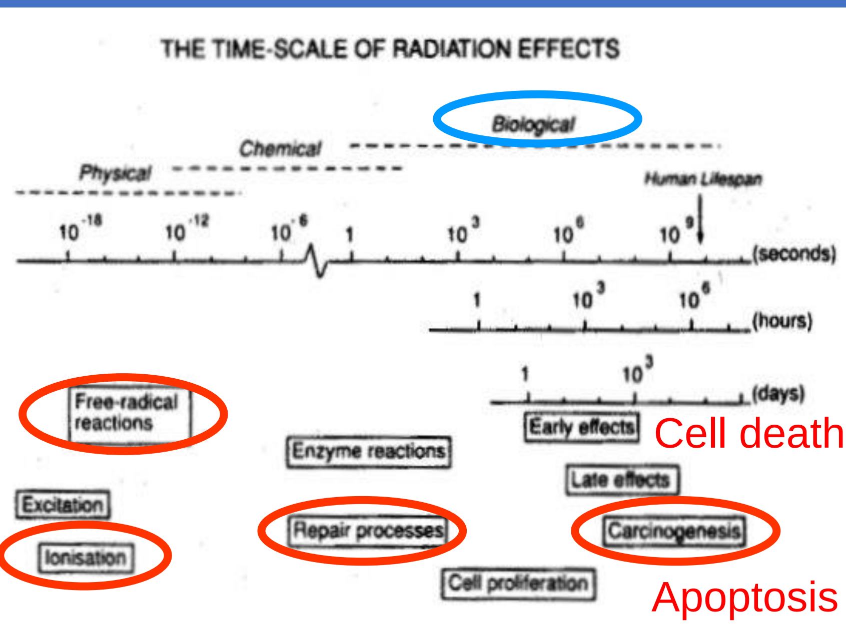
Gamma rays X-rays Neutrinos



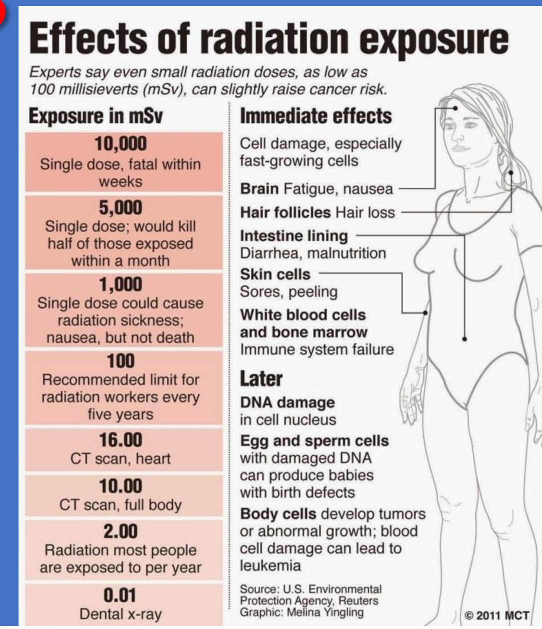


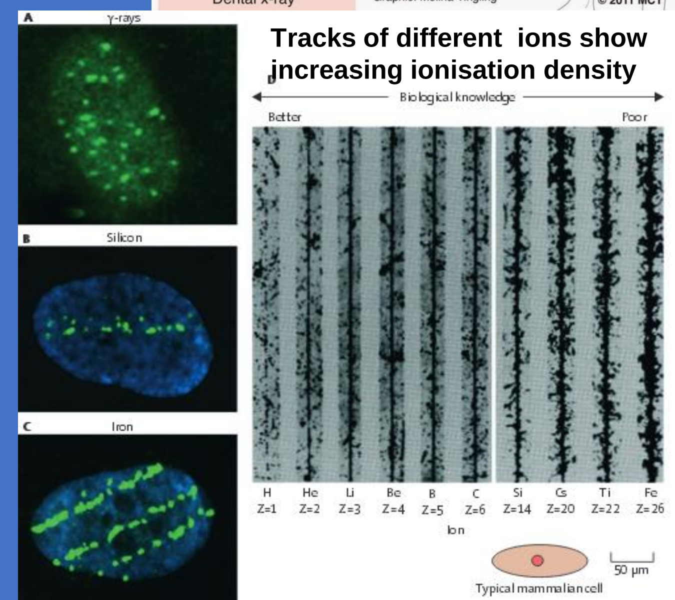
Radiation effects

Due to energy deposition and distribution along the tracks of the radiations



The damage is strictly related to the LET





Linear Energy Transfer (LET)

X ray	0,3 keV/µm
Gamma ray	0,4
Alfa ray	3
Protons	10
Heavy ions	400

How much radiation for aircrew members ?

The National Council on Radiation Protection and Measurements reported that aircrew have the largest average annual effective dose (3.07 mSv) of all radiation-exposed workers. [1]
Others estimate an aircrew cosmic radiation exposure range from 0.2 to 5 mSv per year.

What do guidelines or regulations say about cosmic radiation exposure levels in aircrew ?

European Union member states require assessment of aircrew exposure when it is likely to be more than 1 mSv /year and adjustment of work schedules so that no individual exceeds 6 mSv/year.
There are findings that some crewmembers may have exposure to cosmic radiation that is higher than what is recommended, and thus may be at greater risk for possible health effects.

The National Institute for Occupational Safety and Health (NIOSH)

https://www.cdc.gov/niosh/topics/aircrew/cosmicionizingradiation.html

Radiation effects

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Published by Oxford University Pr
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Airline Pilot Cosmic Radiation and Circadian Disruption Exposure Assessment from Logbooks and Company Records

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Received 8 April 2010; in final form 23 March 2011; published online 24 May 2011

Parameters	Pilot Cumulative	Faculty
Total Effective Dose(ED), mSv	34.4 (10.18--85.25)	0.83 (0.01--9.44)
Total Absorbed Dose, mGy	14.85 (4.54--37.80)	0.37 (0.003--9.44)
Muon ED, mSv	1.52 (0.44--3.75)	0.04 (0.001--0.34)
Muon Absorbed Dose, mGy	1.53 (0.44--3.76)	0.04 (0--0.35)
EMSc ED, mSv	8.78 (2.81--23.23)	0.23 (0.002--2.64)
EMS Absorbed Dose, mGy	8.1 (2.6--21.44)	0.21 (0.002--2.41)
Proton ED, mSv	3.9 (1.16--9.71)	0.09 (0.001--1.1)
Proton Absorbed Dose, mGy	1.72 (0.51--4.29)	0.042 (0.000--0.49
Pion ED, mSv	0.21 (0.07--0.55)	0.005 (0--0.06)
Pion Absorbed Dose, mGy	0.12 (0.04--0.32)	0.003 (0--0.03)
Neutron ED, mSv	19.88 (5.71--48.02)	0.46 (0.005--5.29)
Neutron Absorbed Dose, mGy	3.27 (0.95--8)	0.08 (0.001--0.88)

EPIDEMIOLOGY

Cosmic Radiation Increases the Risk of Nuclear Cataract in Airline Pilots

A Population-Based Case-Control Study

Vilhjalmur Rafnsson, MD, PhD; Eydis Olafsdottir, MD; Jon Hrafnkelsson, MD; Hiroshi Sasaki, MD; Arsaell Arnarsson, MSc; Fridbert Jonasson, MD

Arch Ophthalmol. 2005;123:1102-1105

Table 1. Data From Logistic Regression of Nuclear Cataract Risk Among Cases and Controls According to Employment as a Commercial Airline Pilot, Age, Smoking Status, and Sunbathing Habits

Variable	Controls (n = 374)*	Cases (n = 71)*	Adjusted Odds Ratio (95% Confidence Interval)†
Age, mean, y	66.1	74.6	1.17 (1.12-1.22)
Employment			
Never a pilot‡	310	56	1.00
Ever a pilot	64	15	3.02 (1.44-6.35)
Smoking status			
Never smoked‡	250	12	1.00
Ever smoked	124	59	1.92 (0.92-3.99)
Sunbathing habit			
Not a regular sunbather‡	327	63	1.00
Regular sunbather	47	8	0.91 (0.38-2.20)

Occupational Medicine 2009;59:434–436
Published online 22 May 2009 doi:10.1093/occmed/kqp058

SHORT REPORT

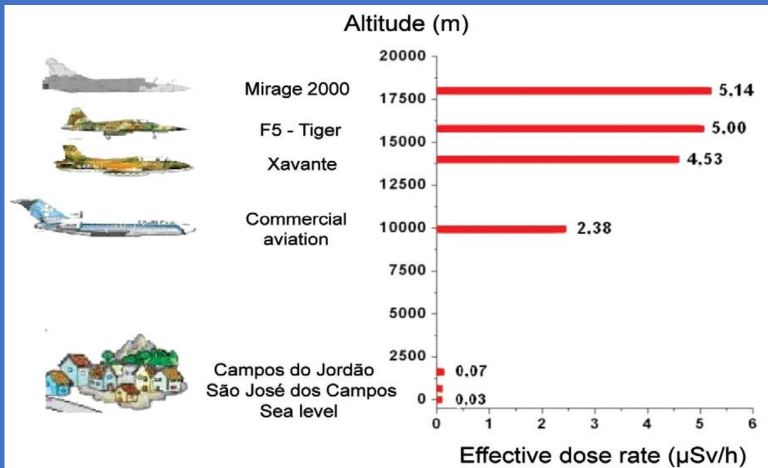
Predictors of skin cancer in commercial airline pilots

Joyce S. Nicholas[1], Christopher J. Swearingen[1] and Jeffrey B. Kilmer[2]

Background Skin cancers among commercial airline pilots have been reported to occur at increased rates in pilot populations worldwide. The reasons for these increases are unclear, but postulated factors include ionizing radiation, circadian disruption and leisure sun exposure.

Aims To investigate the potential association of these occupational and lifestyle factors, as well as medical history and skin type, with non-melanoma skin cancer in pilots.

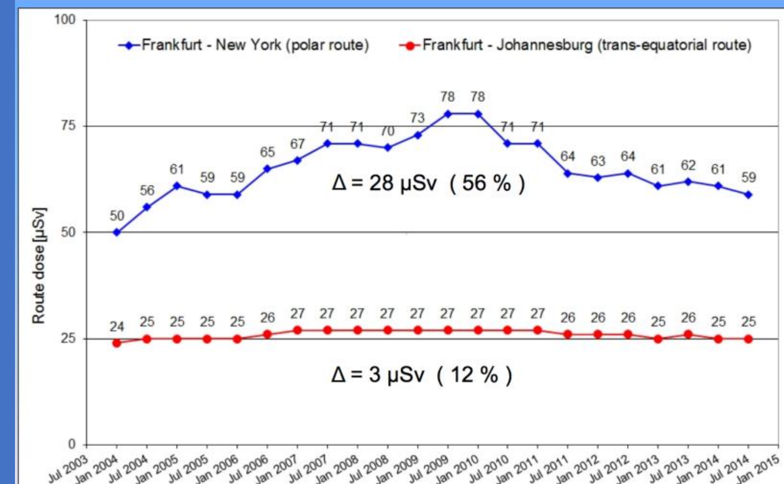
Flight time ≥20 years	OR (95% CI)
Childhood sunburns	1.6 (1.2–2.2)
Flight time at high latitude	1.4 (1.0–1.9)
Non-melanoma family history	4.1 (3.0–5.7)



Gerhard Frasch, Federal Office for Radiation Protection, Germany, 2014

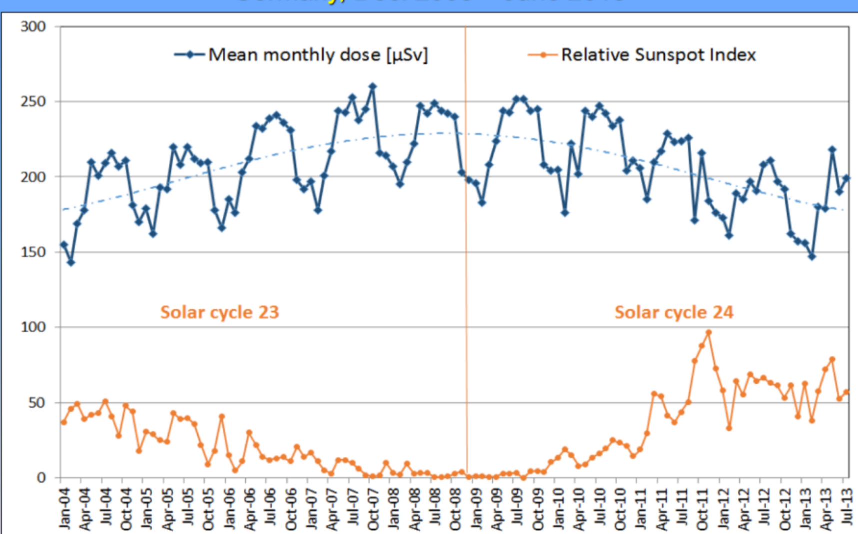
Change of route doses 2004 – 2014

(solar cycles 23 / 24, FRA - JFK, FRA - JHB, Epcard Net 5.4.3)



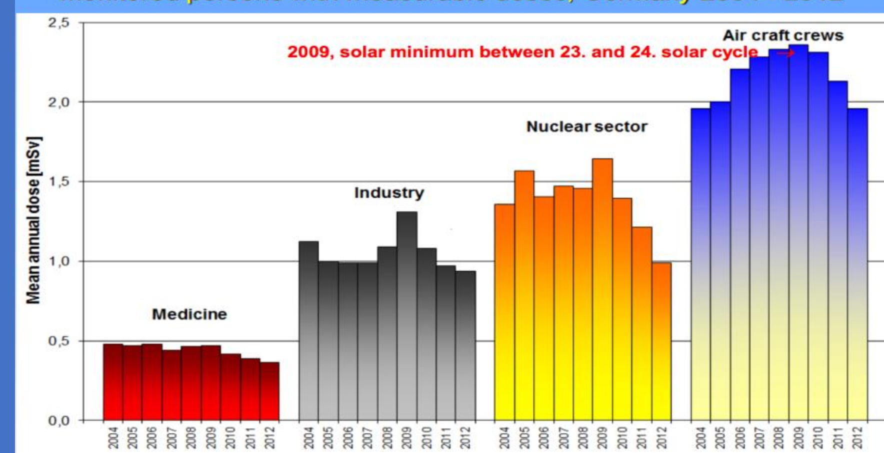
Monthly doses of aircraft crews

Germany, Dec. 2003 – June 2013



Mean annual dose in work sectors

Monitored persons with measurable doses, Germany 2004 - 2012



http://www-ns.iaea.org/tech-areas/communication-networks/orpnet/documents/cn223/7-frasch-presentation.pdf

There are several computer simulation programs able to calculate dose estimates for civil and military aircrews on specific flight routes.

Computer Code	Method based on	Reference	Primary galactic cosmic radiation spectra (if applied)	Cut off rigidity	Dose conversion
AVIDOS 1.0	FLUKA Monte Carlo code calculations	(Beck, 2007; Roesler, 2002)	Gaisser *et al* modified by balloon measurements (Gaisser, 2001; Beck, 2007)	Vertical cut off rigidity (Smart, 1997)	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000)
CARI-6M	LUIN99/LUIN2000 code calculations	(Friedberg, 1992)	below 10 GeV (Garcia-Munoz, 1975), above10 GeV (Peters, 1958) normalized to 10.6 GeV (Gaisser, 1998)	Vertical cut-off rigidity (Shea, 2000) non-vertical cut-off rigidities (Heinrich, 1979)	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000)
EPCARD.Net 5.4.1	FLUKA Monte Carlo code calculations	(Mares, 2009; Roesler,2002)	(Badhwar, 2000)	Vertical cut-off rigidity (Bütikofer, 2007)	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000; Mares, 2007)
FDOScalc 2.0	Experimental data (97-99; 03-06)	(Schrewe, 2000; Wissmann, 2006; Wissmann, 2010)	Not applied	Vertical cut-off rigidity MAGNETOCOSMICS (Desorgher, 2006)	
IASON-FREE 1.3.0	PLOTINUS code calculations	(Felsberger, 2009)	below 10 GeV (Garcia-Munoz, 1975), above10 GeV (Peters, 1958) normalized to 10.6 GeV (Gaisser, 1998)	Vertical cut-off rigidity (Shea, 2000) non-vertical cut-off rigidities (Heinrich, 1979)	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000)
JISCARD EX	PHITS Monte Carlo code calculations	(Yasuda, 2008a; Yasuda, 2008b)	(Nymmik, 1992)	Vertical cut-off rigidity pre-calculated with MAGNETOCOSMICS (Desorgher, 2006)	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000)
PANDOCA	PLANETOCOSMICS 2.0; GEANT4.9.1 Monte Carlo code calculations	(http://corsray.unibe.ch) (http://geant4.web.cern.ch/ geant4/)	(Gleeson, 1968) (Usoskin, 2005)	Vertical cut-off rigidity, pre-calculated with PLANETOCOSMICS 2.0	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000)
PCAIRE	Experimental data (since 97)	(Lewis, 2001; Lewis, 2002; Lewis, 2004; Takada, 2007)	Not applied	Vertical cut-off rigidity (Lewis, 2002)	ICRP 60 (ICRP, 1990)
PLANETOCOSMICS 2.0	GEANT4 Monte Carlo code calculations	(http://corsray.unibe.ch)	(Gleeson, 1968; Garcia-Munoz, 1975)	Vertical cut-off rigidity (Bütikofer, 2007)	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000)
QARM 1.0	MCNPX Monte Carlo code calculation	(Lei, 2004; Lei, 2006; Dyer, 2007; http://mcnpx.lanl.gov)	(Badhwar, 2000)	Vertical cut-off rigidity (Smart, 1997)	ICRP 74 (ICRP, 1996), (Pelliccioni, 2000)
SIEVERT 1.0	EPCARD version3.3.4 code calculations	(http://sievert-system.org; Bottollier-Depois, 2007)	(Badhwar, 2000)	Vertical cut-off rigidity (Smart, 1997)	ICRP 60 (ICRP, 1990) (Pelliccioni, 2000)

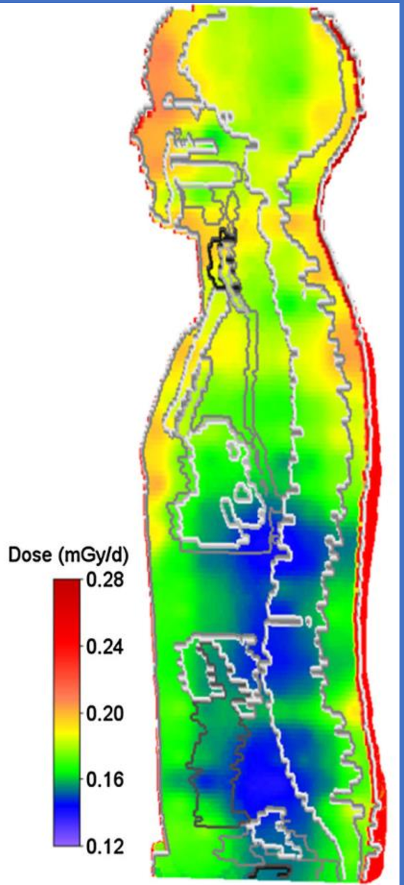
The data required are: the date of departure, the location of departure, the flight profile, detailing the time in ascent, cruise and descent, and the arrival location.

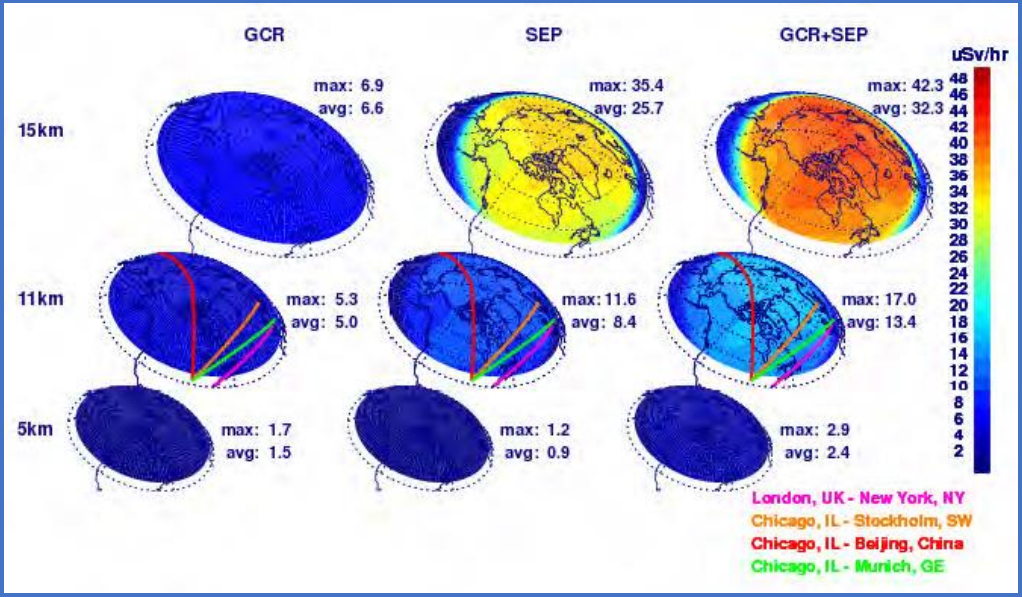
All programs require regular updating, especially for the effect of solar modulation and for changes in geomagnetic field conditions.

Flight (from Istanbul)	Flight Time (hh:mm)	CARI	EXCEL	SIEVERT	Difference (%)
Helsinki	2:40	7.0	7.1	9.8	1.43
New York	10:19	55.9	57.0	56.9	1.97
Tokyo	11:14	43.3	46.3	52.0	6.93
Johannesburg	9:03	22.3	22.1	18.7	-0,90

Flight date: 1/6/2014.

CARI-7 , recent upgrade of CARI-6 code, calculates the dose of galactic radiation on aircrew members

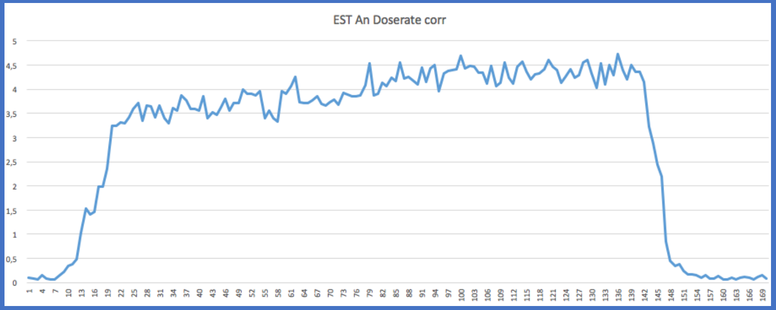




We decided to verify the accuracy of CARI-7 code by assessing a basic level of radiation exposure (only ionizing events), in real-time, and making a comparison with CARI-7 simulation data in retrospective.

Radiation exposure was assessed on five military flights, of different contexts in terms of Altitude (range 25kft-37,8kft) and Latitude (range 41-59), using the CARI-7 computer program in a retrospective way.

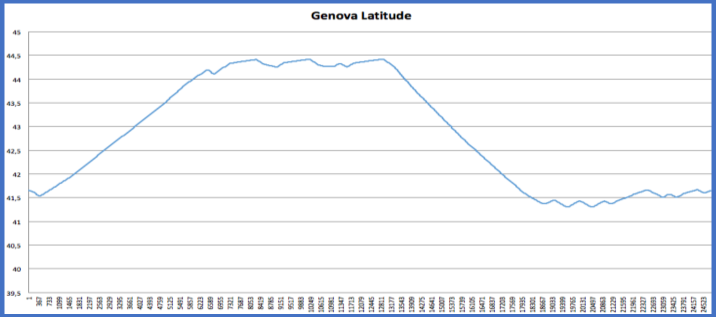
For the real-time detection we used on board (cockpit) a simple and very light geiger detector (Gamma-Scout w/Alert, certified) with data logger, to evaluate the exposition related to photons and charged particles.

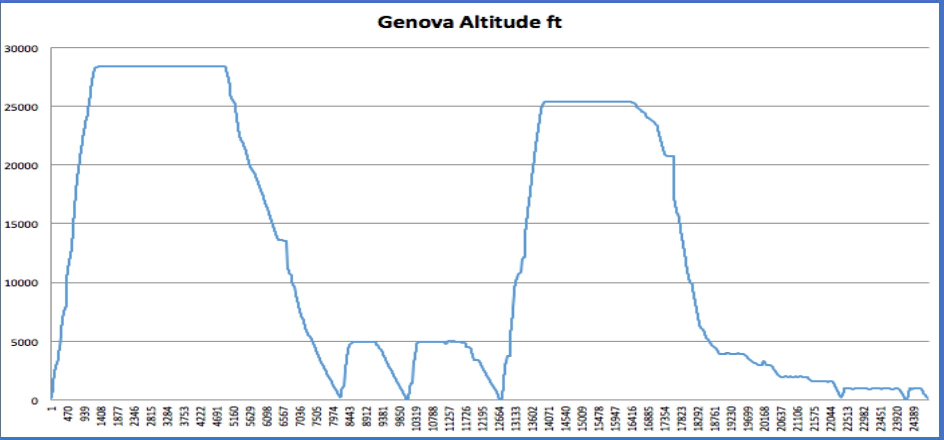


Finally we made a comparison of the on board recorded dose with the calculated one.

Some measurement results

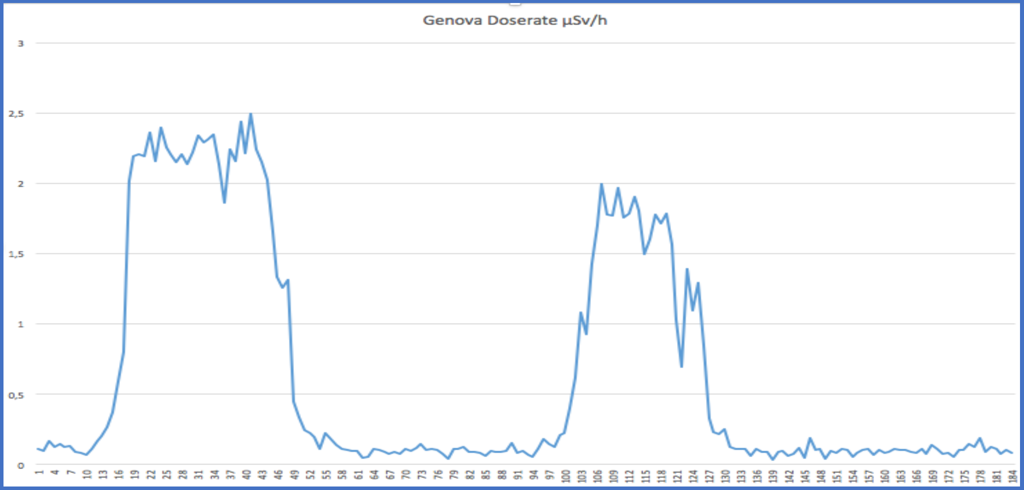
Flight Rome-Genoa-Rome: 2.75 hours





FLIGHT FROM LIRE-LIRE.DEG
GCR MODEL 4 TRANSPORT AND CUTOFFS: 0 SUPERPOSITION: 0
DATE: 2016/12/00 HOUR: 0
3.2486E+00 TOTAL microSv, ICRP Pub. 103 EFFECTIVE DOSE

CARI-7, 3.2 µSv

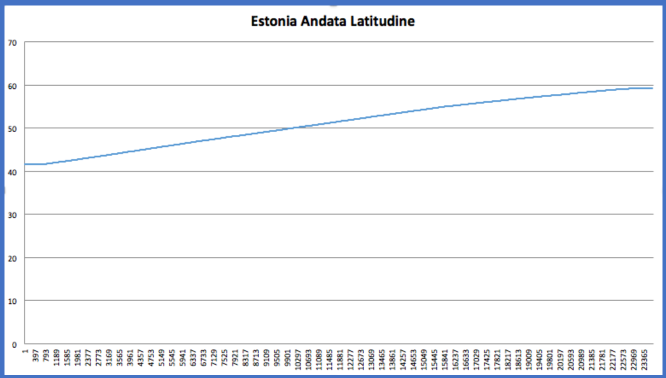


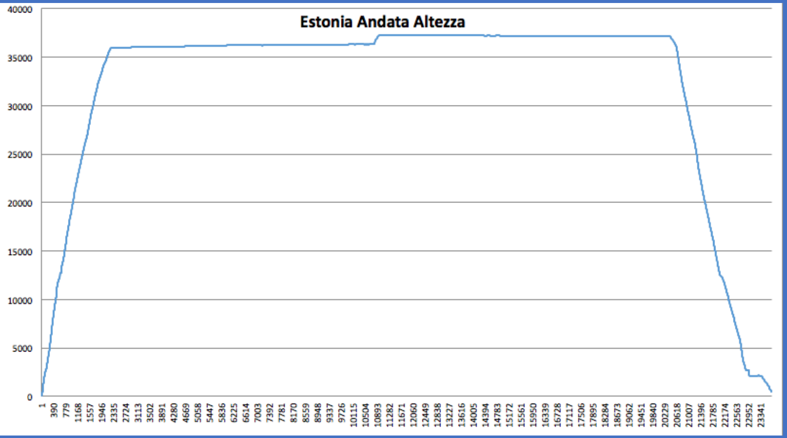
Gamma Scout, 2.4 µSv

Gamma Scout dose 30 % lower than CARI-7

Some measurement results

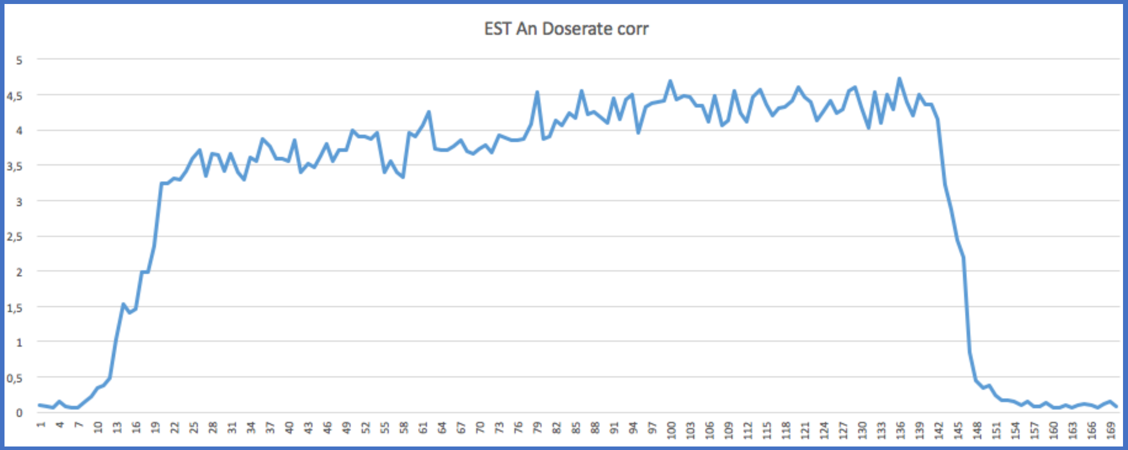
Flight Rome-Amari (Estonia): 2.65 hours





FLIGHT FROM LIRE-AMARI.DEG
GCR MODEL 4 TRANSPORT AND CUTOFFS: 0 SUPERPOSITION: 0
DATE: 2016/12/00 HOUR: 0
9.6199E+00 TOTAL microSv, ICRP Pub. 103 EFFECTIVE DOSE

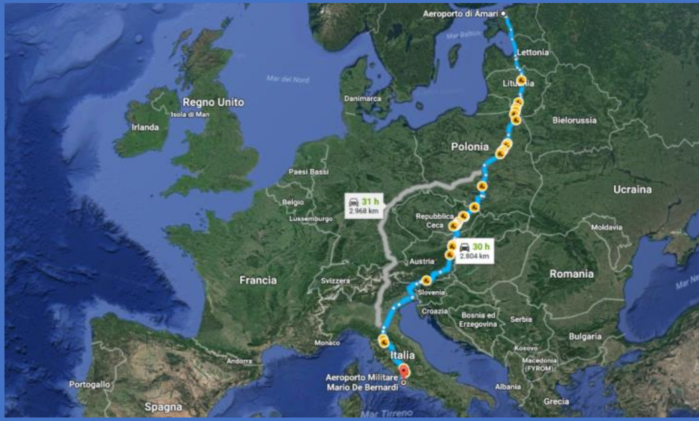
CARI-7, 9.6 µSv



Gamma Scout, 8.69 µSv

Gamma Scout dose 12,5 % lower than CARI-7

Some measurement results

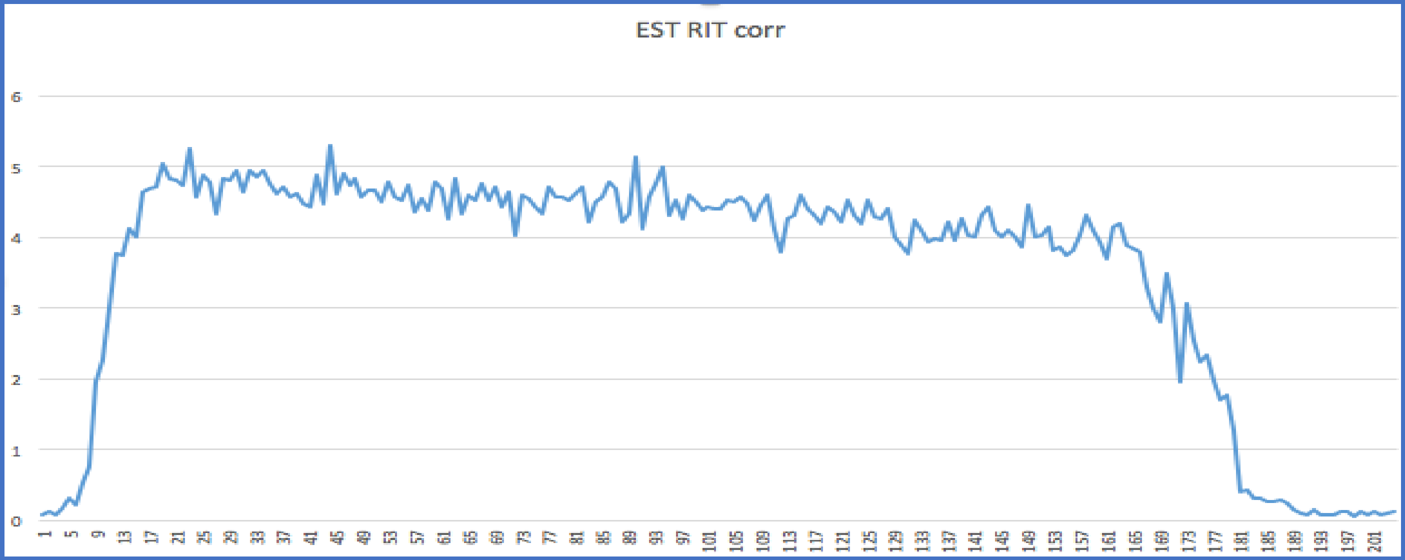


Flight Amari (Estonia) to Rome: 3.2 hours

Back flight, with longer duration

FLIGHT FROM AMARI-LIRE.DEG
GCR MODEL 4 TRANSPORT AND CUTOFFS: 0 SUPERPOSITION: 0
DATE: 2016/12/00 HOUR: 0
1.2185E+01 TOTAL microSv, ICRP Pub. 103 EFFECTIVE DOSE

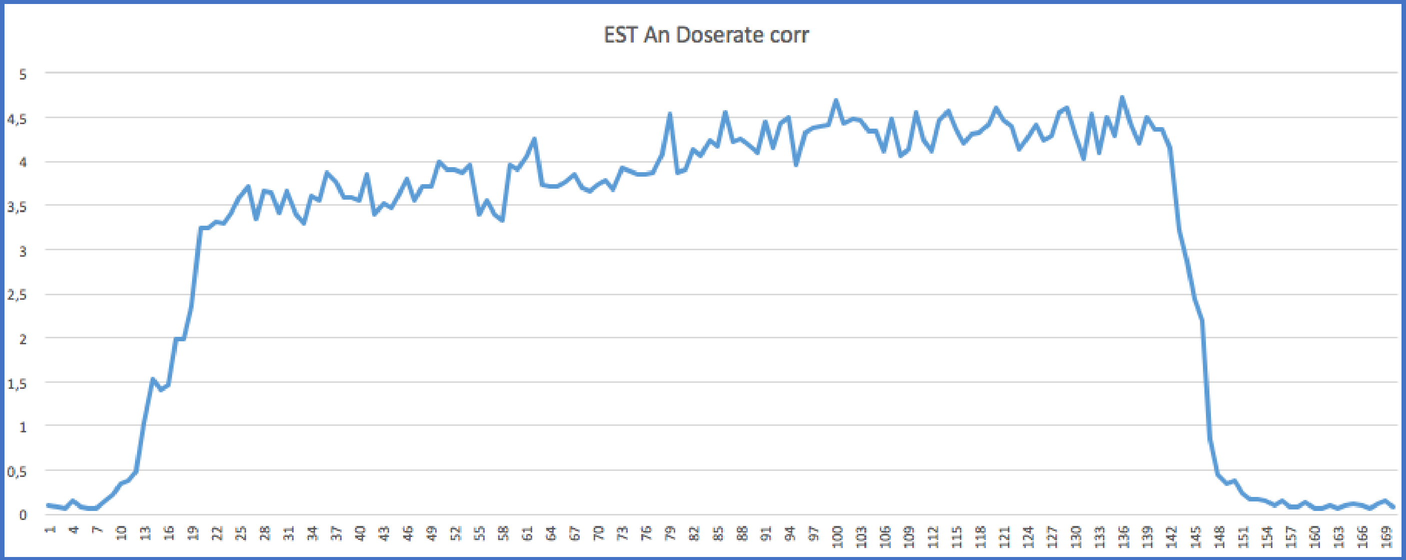
CARI-7, 12.2 µSv

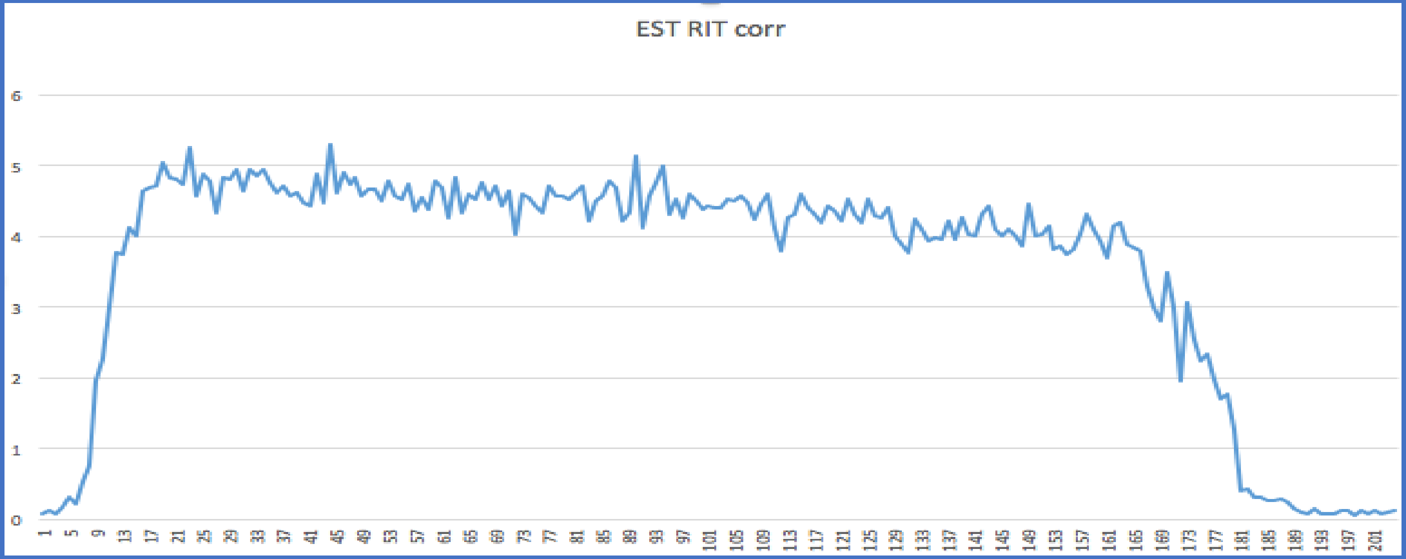


Gamma Scout, 13.2 µSv

Gamma Scout dose 8,3 % higher than CARI-7

Global flight Rome-Amari (Estonia)-Rome





Very good antisymmetry of the two graphs due to the latitude differences

Some considerations ……….

J. Astron. Space Sci. 27(1), 43–54 (2010)

Space Radiation Measurement on the Polar Route onboard the Korean Commercial Flights

Junga Hwang[1†], Jaejin Lee[1], Kyung-Suk Cho[1], Ho-Sung Choi[1,2], Su-ryun Rho[1], and Il-Hyun Cho[1]
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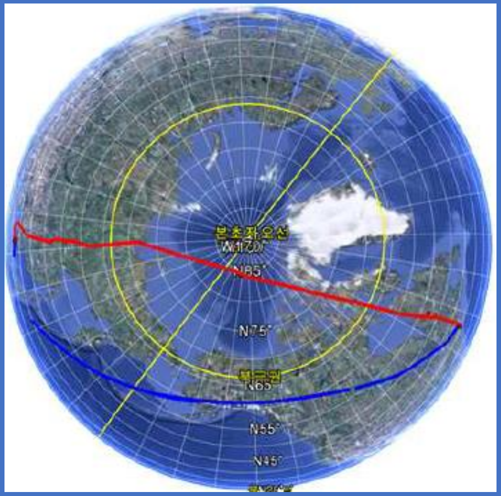
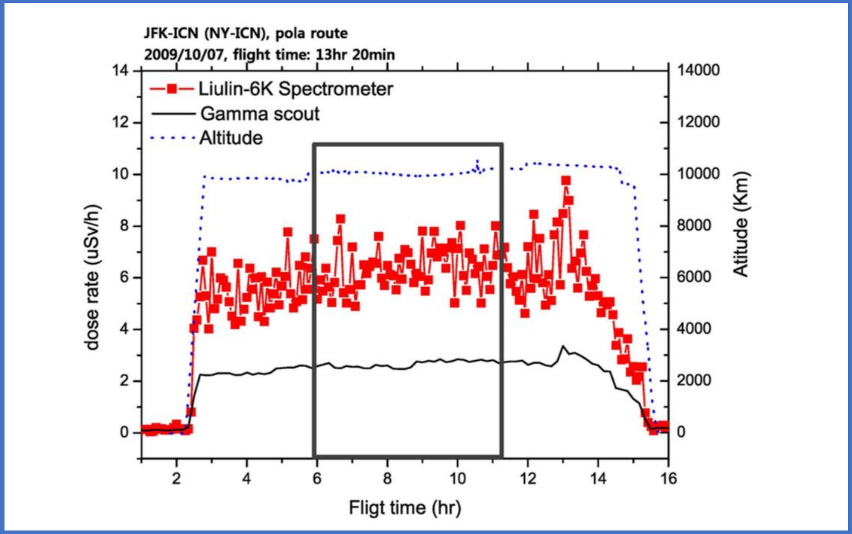
[2]University of Science and Technology, 113 Gwahangno, Yuseong-gu, Daejeon 305-333, Korea
E-mail: jahwang@kasi.re.kr

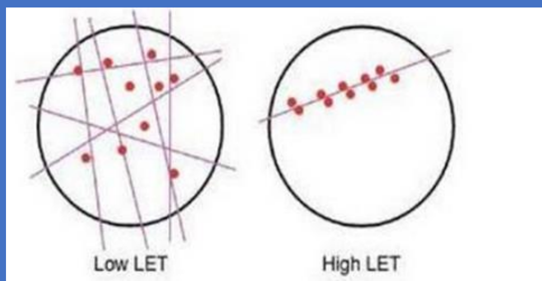




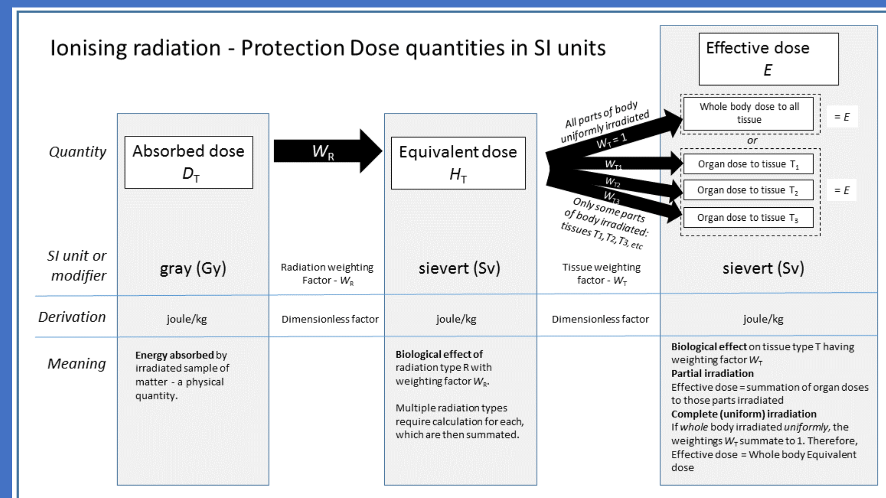
- Similar data between measured value and simulation value using CARI-6M software.
- It is not so different to use or not to use the polar route because the higher latitude effect is compensated by a shorter flight time.

Some considerations ……….

While CARI-7 proved to be good for calculation of doses to aircraft crew, with error margins within 20-30%* of the measured median, the problem of the biological effects of cosmic radiations still remain open, due to the existing differences between low and high LET radiations

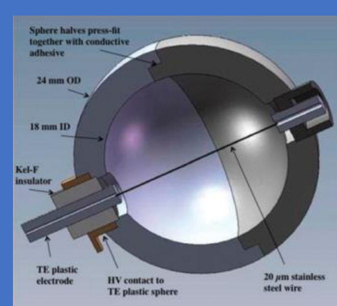


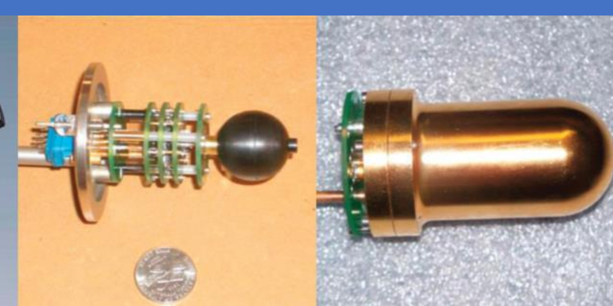
Both examples produce the same total number of ionizations, thus represent the same dose, but with different effects by Low LET and High LET



Tissue Equivalent Proportional Counter (TEPC)

*European Commission, Radiation Protection 140, 2004





Some considerations ……….

Considering the large variability in cosmic rays exposure, depending from the different flight routes, different altitude, different latitude and period of the solar cycle, in some cases, expecially for military aircrew, the individual limit of 6 mSv/year in the European Union countries could be exceeded.

New materials could be used to shield radiations

NATURE MATERIALS | ARTICLE

Large-area high-quality 2D ultrathin Mo_2C superconducting crystals

Chuan Xu, Libin Wang, Zhibo Liu, Long Chen, Jingkun Guo, Ning Kang, Xiu-Liang Ma, Hui-Ming Cheng & Wencai Ren

Affiliations | Contributions | Corresponding authors

Nature Materials **14**, 1135–1141 (2015) | doi:10.1038/nmat4374
Received 26 February 2015 | Accepted 01 July 2015 | Published online 17 August 2015

Approaching the Limits of Transparency and Conductivity in Graphitic Materials through Lithium Intercalation

Wenzhong Bao[(a),1,2], Jiayu Wan[(a),2], Xiaogang Han[2], Xinghan Cai[1], Hongli Zhu[2], Dohun Kim,[1] Dakang Ma[3], Yunlu Xu,[3] Jeremy Munday[3], H. Dennis Drew[1], Michael S. Fuhrer[*,1,4], Liangbing Hu[*,2]
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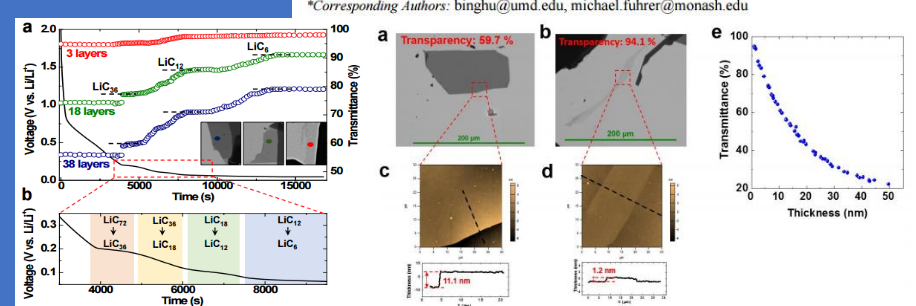

Some considerations ……….
on perspectives

Regarding very high quote & latitude flights, it is mandatory to focus, in the near future, on two main objectives:

- **a more accurate dose evaluation, using adequate measurement devices, able to operate at different particles energies (Tissue Equivalent Proportional Counter)**

- **an exposure reduction of aircrew using organizative and shielding solutions.**

and as reccommended in ICRP 132 (2016):

(i) inform the aircraft crew individually about cosmic radiation through an educational programme;
(ii) assess the dose of aircraft crew;
(iii) record the individual and cumulative dose of aircraft crew. These data should be made available to the individuals and should be kept for a reasonable period of time that is, at a minimum, comparable with the expected lifetime of the individuals;
(iv) adjust the flight roster when appropriate, considering the selected dose reference level and after consultation with the concerned aircraft crew.

Final considerations

Aircrew exposure to cosmic ray is still an open issue.

The cumulative dose, along the years, is not negligible, expecially for pilots.

We need a more accurate evaluation of the different energies of the particles (low LET versus high LET).

We need to propose organizative and shielding solutions to reduce the pilot exposure