NATURAL RADIATION AT AIRCRAFT ALTITUDES: FACTS VS. FICTION

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SYNOPSIS

When the effects of radiation at aircraft altitudes are discussed,
a mix of real and perceived effects often confuses the general public.

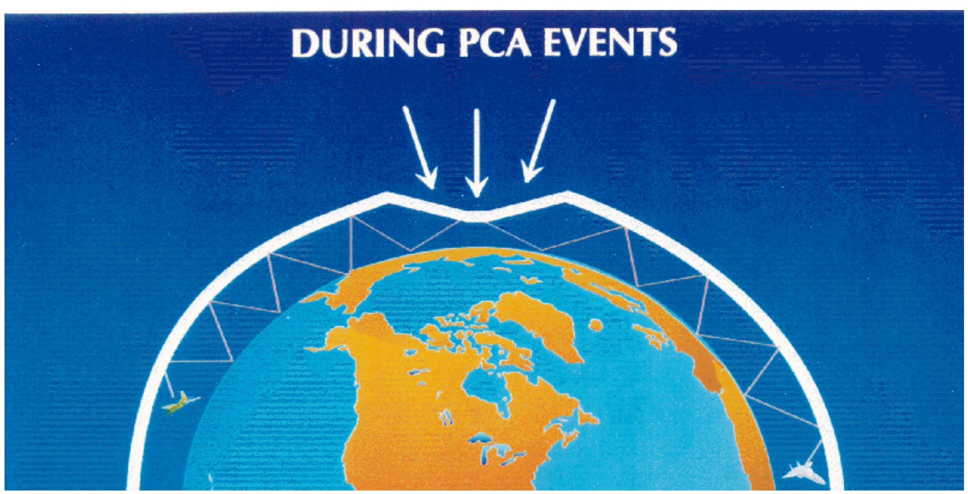
The effect of solar protons and X-rays on HF communications is a real phenomenon.
There is confusion with respect to radiation exposure to air crews and the public.

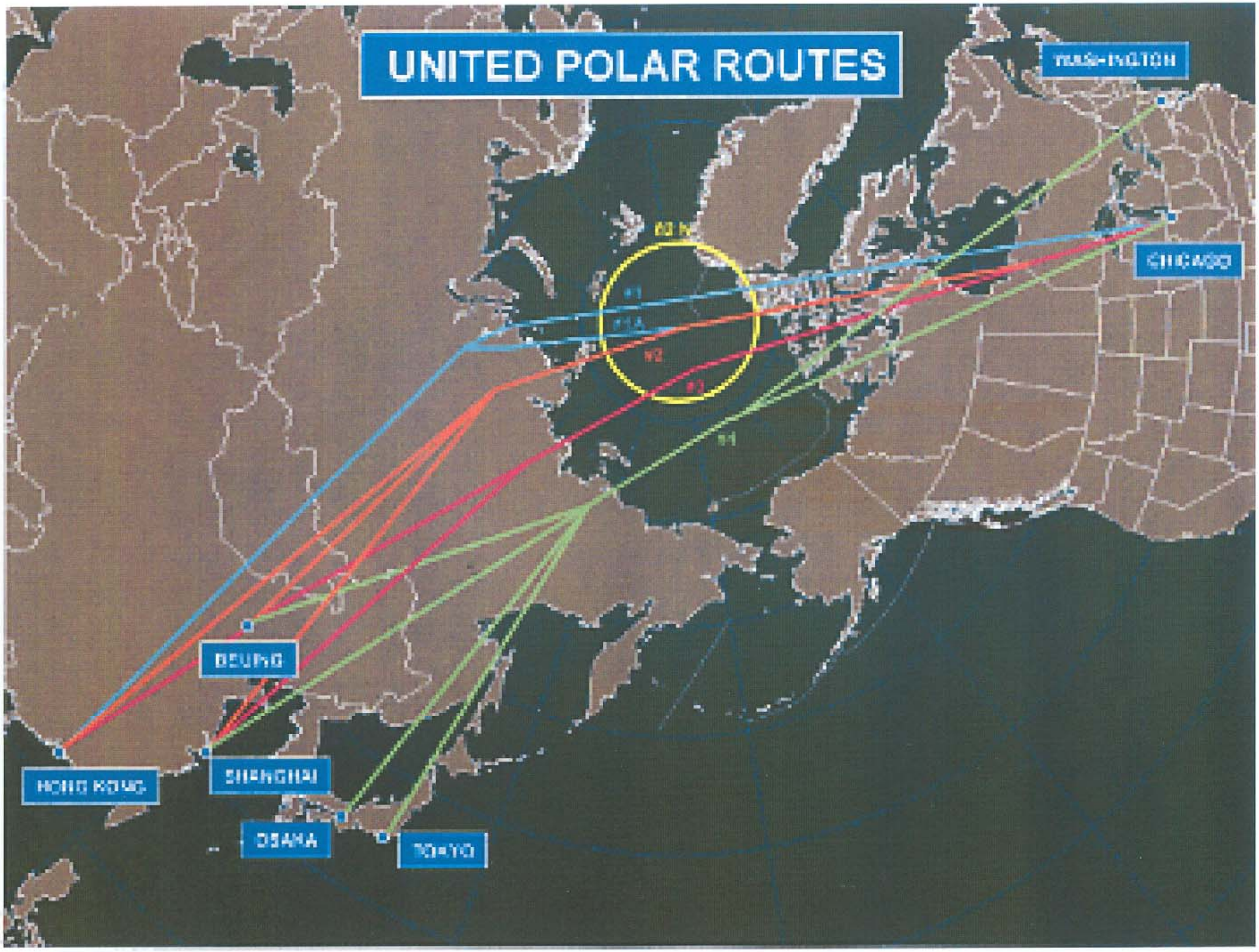
Unfortunately, owing to a public perception that radiation is dangerous,
bad estimates, myths, and urban legends seem to be pervasive.

Radiation dose calculations are being verified by in-flight dosimeters on a variety of routes around the world. These investigations show that since 1986 **there have been no solar proton events that would pose radiation hazards to the general public.**

Aircraft hazard overview

Observable	Effect	Elapsed Time
Background Radiation		
Galactic Cosmic Radiation	Low Radiation dosage Modulated during ~11-year solar cycle: Maximum intensity = solar minimum Minimum intensity = solar maximum	Always present
Transient Events		
Solar X-rays	HF communication problems (Daylit side only)	Hours
Solar Protons	HF communication problems (Polar regions)	Hours to Days
	Increase above background radiation Possible electronic interference	Hours to Days



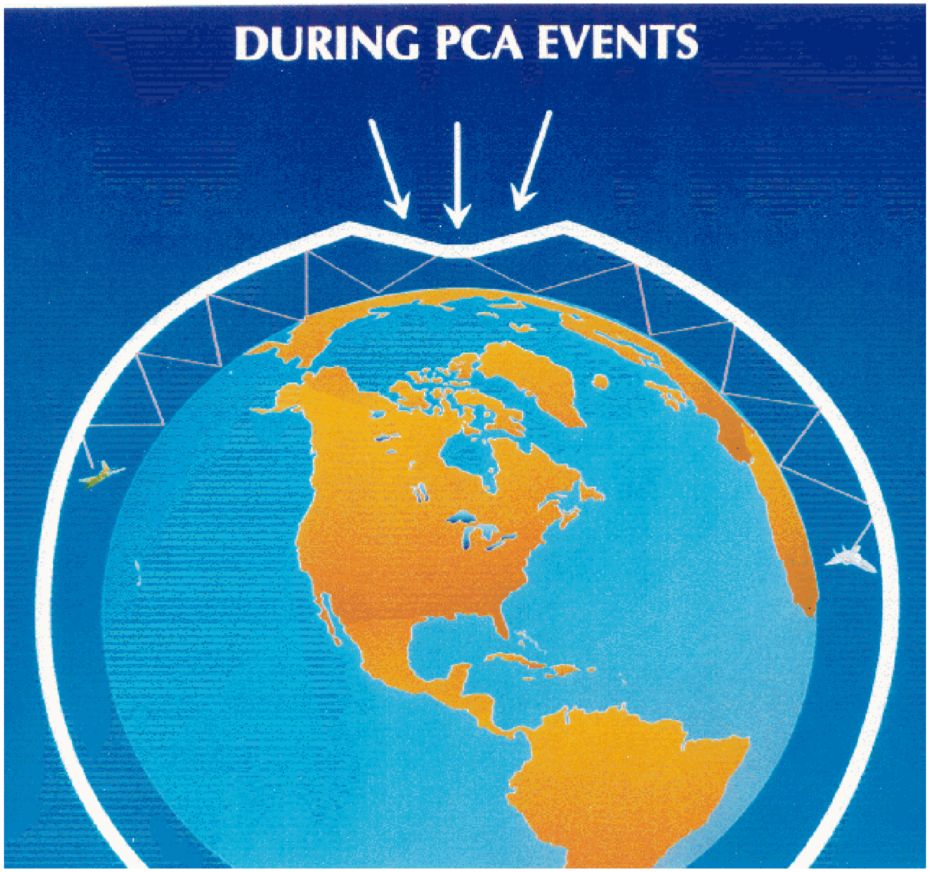

UNITED POLAR ROUTES
WASHINGTON
CHICAGO
#1
#1A
#2
#3
#4
BEIJING
HONG KONG
SHANGHAI
OSAKA
TOKYO

REAL PROBLEM COMMUNICATIONS

The solar activity effect on HF communications is a real phenomenon.

Recordings of the GPS errors at Thule, Greenland during large PCA events demonstrate that the errors were within the acceptable range for navigation.

The GPS error rates for controlling a landing during a very severe ionospheric disturbance is currently a **technically challenging problem**, but this should not be confused with a polar navigation problem.



ELECTRONIC INTERFERENCE SUMMARY

There are reports of satellite electronics failures being the result of cosmic ray interactions in solid-state electronic devices. These occur at random but are most prevalent during large high energy solar proton events

These are usually the result of poor design that failed to consider the effects of space radiation on devices that function well on the earth's surface.

This leads to speculation that similar effects might occur in aircraft.

There are Boeing Technical reports that predict total reliability of the Boeing 777 avionics during the most severe solar cosmic ray event recorded.

www.boeing.com/associated products/radiationlab/publications

Two papers with technical details and references that may be of interest

"Single Event Upset at Ground Level" and

"Single Event Effects in Avionics".

The AirBus has redundant electronic including triple redundancy for the most critical systems

REGULATORY BACKGROUND AND LIMITS

Organization	Period	Acceptable Dosage for <u>General public</u>
ICRP	**< 1991**	**100 milli Sv/year**
	> 1991	**20 milli Sv/year**
		Acceptable Dosage for <u>embryo-fetus</u>
NCRP (USA)	**< 1993**	**2 milli Sv/month**
	> 1993	**0.5 milli Sv/month**

The decrease in the acceptable dosage re-opened the entire issue of aircraft radiation safety.

Facts:

Background radiation dose at 40,000 feet — **~ 3** micro Sv per hour (Equatorial)

6-9 micro Sv per hour (Polar regions)

RADIATION OVERVIEW

Determination of radiation dose hazard involves the following:

Knowledge of particle flux at the top of the atmosphere
- Spacecraft measurements

Knowledge of the nuclear cascade in the atmosphere
- Modeling programs

Calculation of the radiation dosage as a function of altitude
- Modeling programs

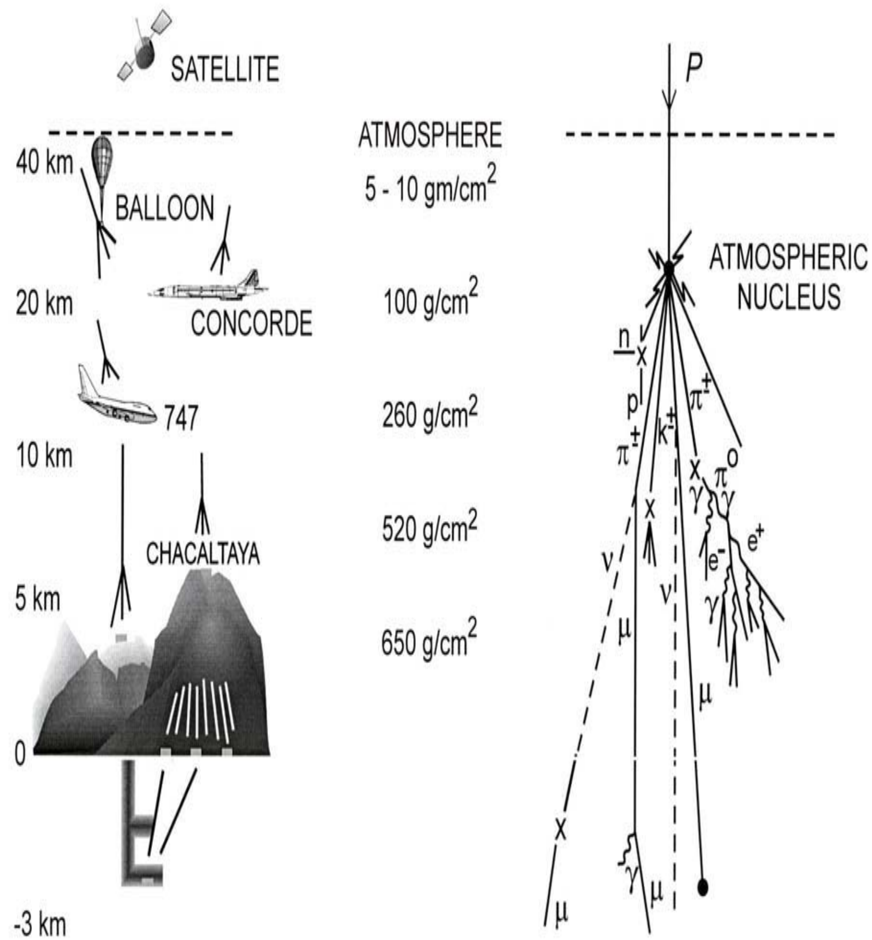
Radiobiological effects
- Significant problem.

Calculation of nuclear cascades in the atmosphere.

Modeling the high-energy nucleon cascade in the atmosphere is a technically difficult problem that is being addressed using modern super computers.

In the last year the high-energy nuclear cascade models have been extended to determine the radiation dose in the atmosphere for solar cosmic ray events.

These recent determinations are limited to the events that occurred in the last ~20 years when there are good spacecraft measurements of the solar particle flux and spectra.



National differences in addressing the aircraft radiation safety issue.[1]

The aircraft radiation safety issue is of societal interest.

The principal problem is the inability of the radiation specialists to provide a definitive answer to the public question of what is "**safe** and **not safe**".

The European countries embarked on a program of measurement and mandated passenger record keeping.
(Council Directive 96/29/Euratom of 13 May 1996).

There are many models that predict the cosmic ray dose at aircraft altitudes

ACREM	(European, Commercial)
CARI	**(USA FAA)**
EPCARD	**(European)**
FREE	
PCAIRE	(Canada)
SIEVERT	(French)
PLOTINUS	

All of these cosmic ray dose codes give consistent radiation dose predictions for galactic cosmic rays

There is NOT a similar consistency for radiation dose predictions from high energy solar protons

Technical problem - Radiobiological effects

There is a serious deficiency in the knowledge of fundamental radiobiological effects of high-energy nucleon radiation. This has been emphasized in the US National Academy and NCRP reports.

There are unresolved issues regarding the health risk from exposure to low levels of ionizing radiation.

Most radiation risk estimates are based on X-ray radiation with a quality factor being applied to estimate the effects of other types of radiation.
However, there are significant differences between the effect of exposure to X-ray radiation and exposure to high-energy nucleon radiation.

This problem may not be resolved for decades!

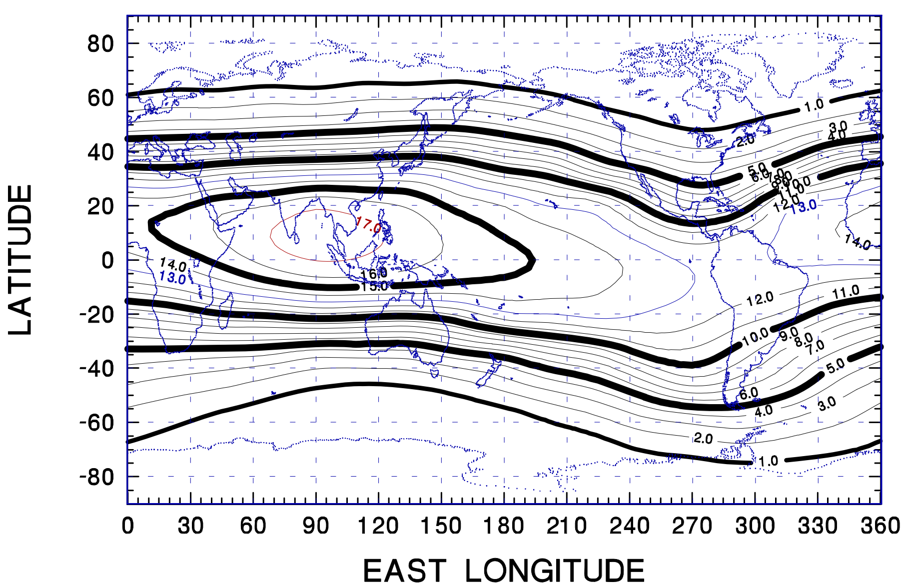
Mitigating and Complicating Factors

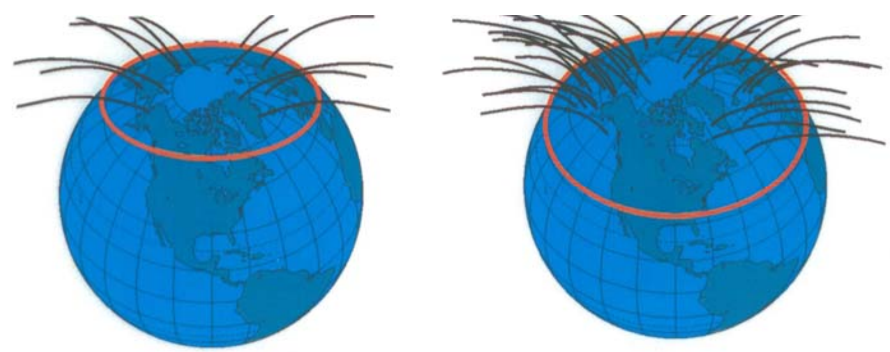
The geomagnetic field provides shielding for the earth.
Protons > 500 MeV can impact the polar atmosphere.
Only protons > ~14 GeV can impact the equatorial atmosphere.

During major geomagnetic storms, the polar cap regions are enlarged.
Particles that previously could not impact upper mid latitudes
now have access to those regions.

The anisotropy of the solar particle flux can be extreme; however,
these conditions typically last less than an hour.

VERTICAL CUTOFF RIGIDITIES (GV)
2000 IGRF





NORMAL GEOMAGNETIC CONDITIONS

SEVERE GEOMAGNETIC DISTURBANCE

"Urban Legends"

When the first solar cosmic ray events were measured in the 40's and 50's, there was considerable speculation on what the radiation dose would be.

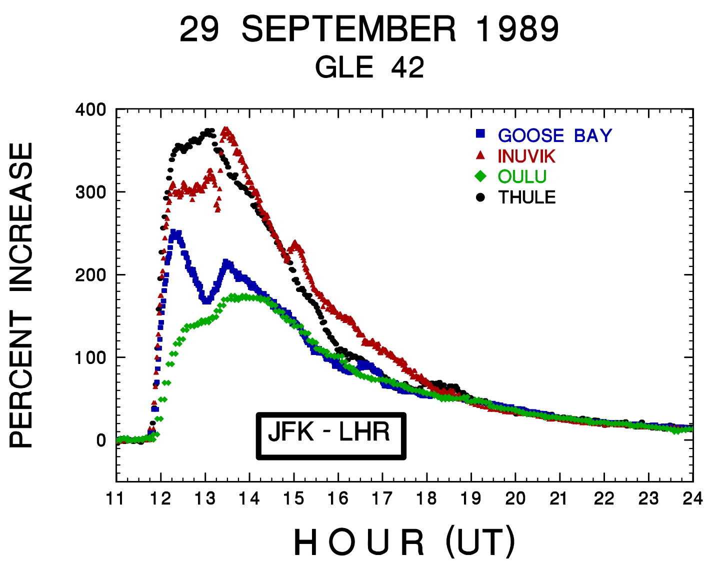
The large and energetic solar cosmic ray event on 23 February 1956 and the large events in November 1960 provided opportunity for further speculations.

Based on the very crude measurements of the particle spectra and flux, and using the technology of the 1960's, predictions of the radiation dose were made.

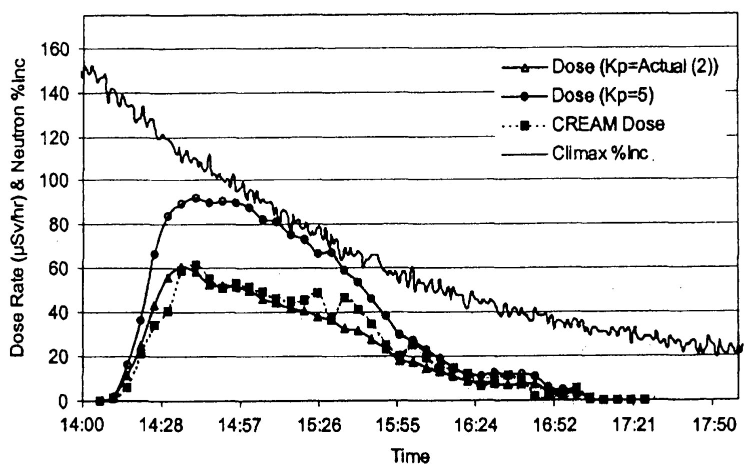
These predictions have been proven to be wrong by being too large by orders of magnitude.

The more recent and technically correct calculations are almost never referenced, and these initial bad values persist as urban legends.

Observed radiation dose on the CONCORDE on 29 September 1989



Increase observed at N. polar neutron monitors
Third largest (hourly avg) ever observed



29 September 1989, JFK-LHR flight

The radiation observed on the JFK-LHR Concorde flight as derived from CREAM measurements. (Dyer et al., ASR, 32, 81, 2003)

Top line - the Climax CO neutron monitor.

Center line is the predicted dose rate if the flight had occurred during a severe geomagnetic storm.

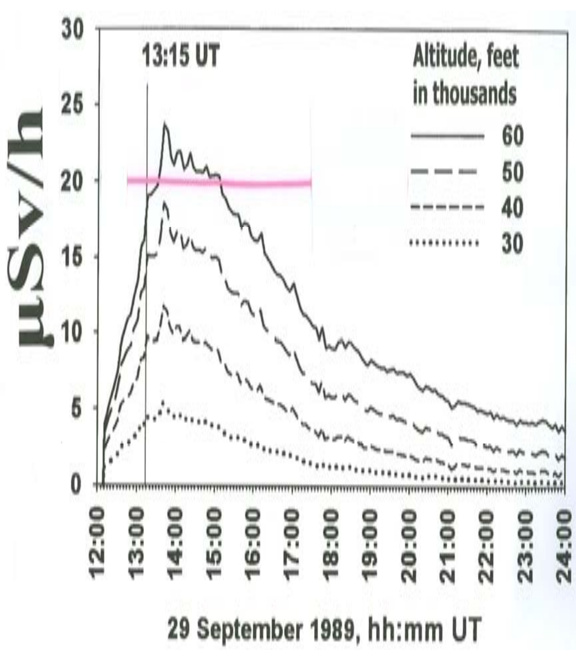
Lower lines indicate the dose rate for the actual flight conditions.

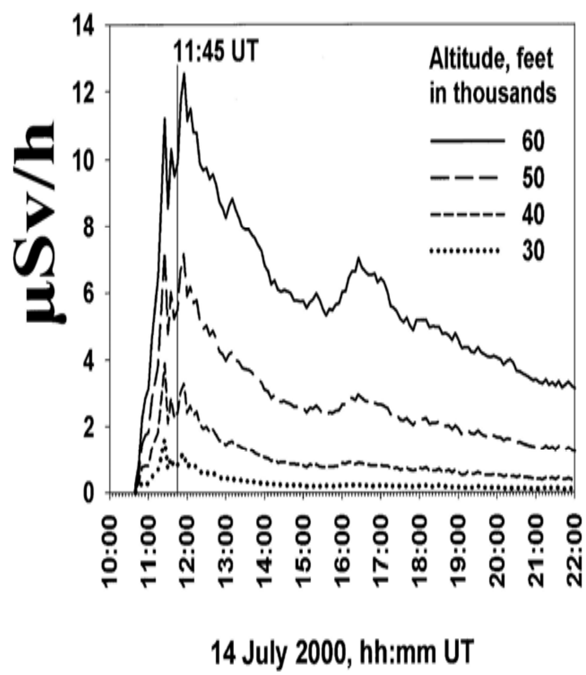
Dose		Limit Adult	Limit Fetus
~0.070	milli Sv	20.0	0.5

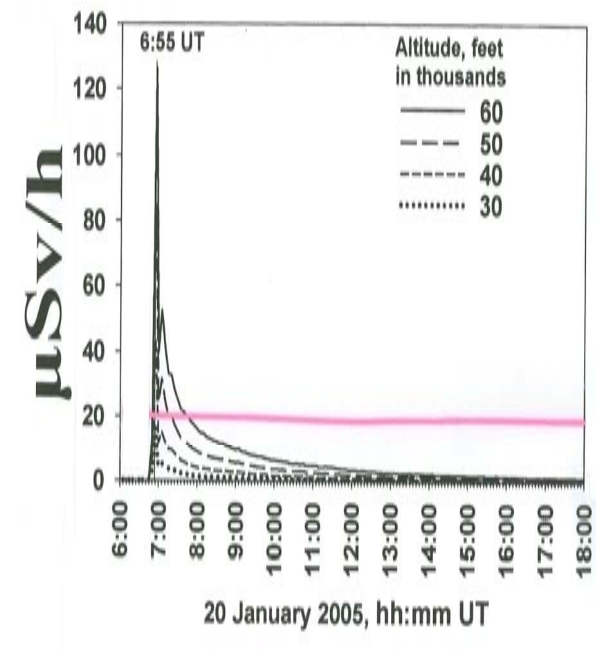
Computed polar latitude radiation dose for the three largest solar cosmic ray events in the last 20 years.
(Source Copeland and Friedberg, 2006)

For 10 hours, 40,000 ft altitude, N Pole

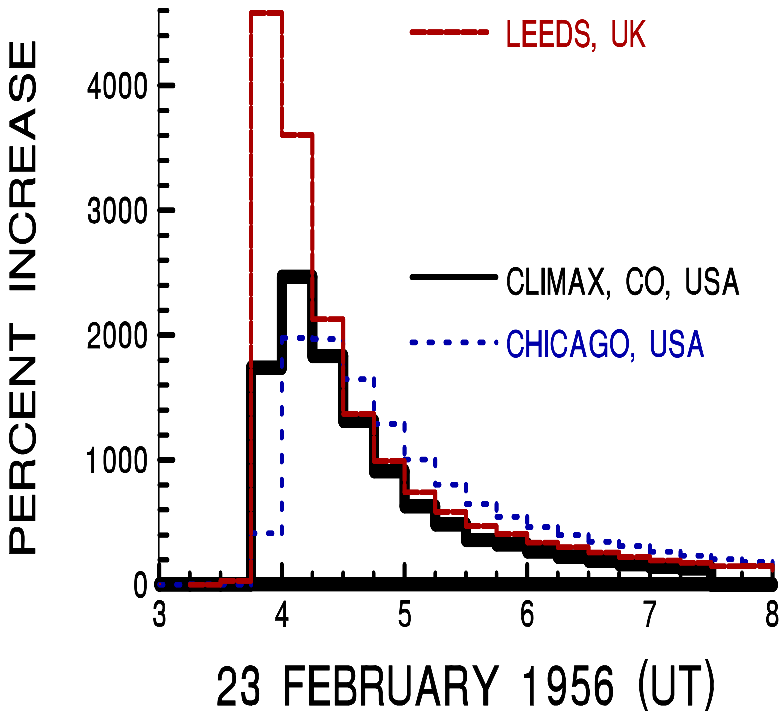
Date	Solar	GCR	Total		ADULT LIMIT	FETUS LIMIT
1989 09 29	**0.935**	**0.066**	**0.101**	**milli Sv**	**20.0**	**0.5**
2000 07 14	**0.009**	**0.058**	**0.067**	**milli Sv**	**20.0**	**0.5**
2005 01 20	**0.016**	**0.051**	**0.066**	**milli Sv**	**20.0**	**0.5**



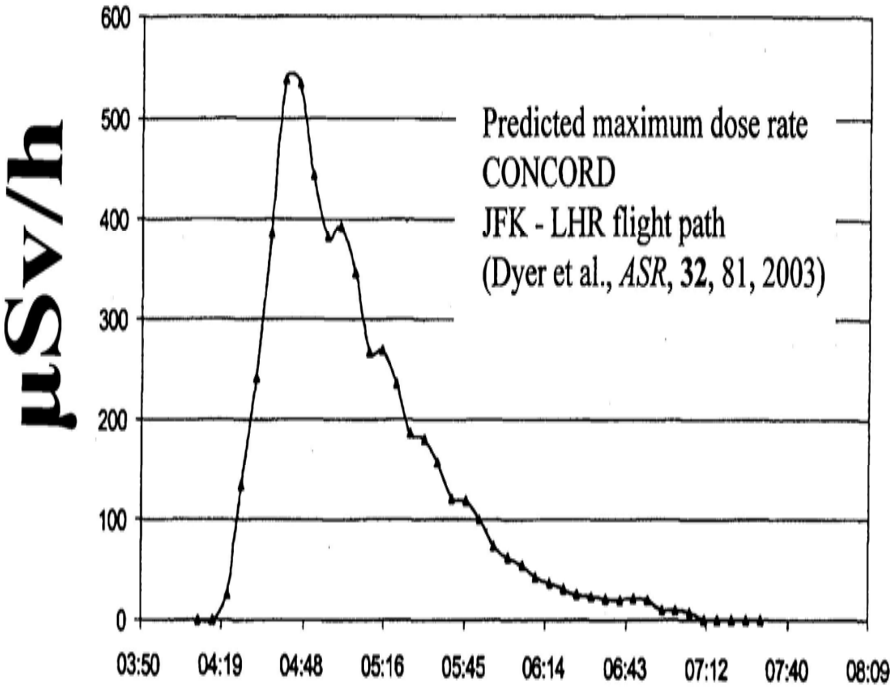




Predicted worst case for a hypothetical Concorde flight from JFK-LHR during the maximum of the very large solar cosmic ray event of 23 February 1956



Dyer et al. used the 29 September 1989 event for calibration with the Climax, Colorado, USA neutron monitor data



Dose	Limit Adult	Limit Fetus
~0.5 milli Sv	20.0	0.5

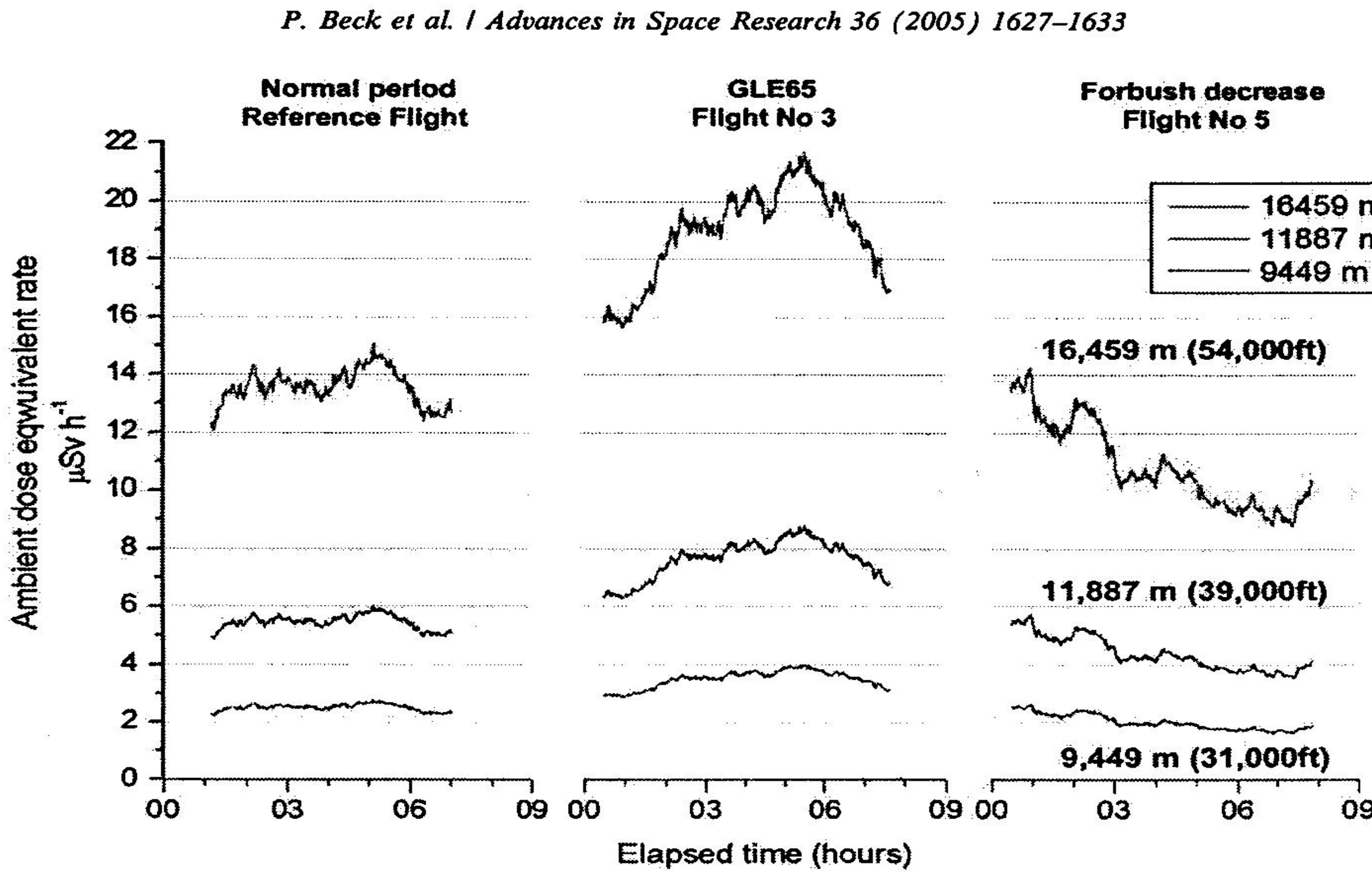
Comment regarding aircraft radiation dose during a solar cosmic ray event.

The contemporary modern numerical calculations of the expected radiation dose at commercial flight altitudes of ~40,000 feet predict a total solar cosmic ray dose that is about the same as the dose received from the galactic cosmic rays during a flight along the North Atlantic Air corridor.

There are actual measurements of the radiation dose for some of the solar cosmic ray events of the past 10 years.
These measurements are relatively consistent with numerical calculations.

There are measurements of the radiation dose during the Halloween 2003 events. Articles in *Space Weather 2 (S05002)* & Space Weather 3 by *Getley et al. (S01004)* show that the total radiation dose (including the solar cosmic ray event) was actually less than the normal quiescent flight exposure.

The Munich-Chicago flights also indicated that the total radiation dose was actually less than the normal quiescent flight exposure *(Beck et al. ASR 36, 2005)*.



Prediction for the 28 October 2003 Chicago-Munich flight if the solar cosmic rays added to normal GCR radiation dose

SUMMARY

There are a number of tools available that accurately predict the cosmic radiation dose at aircraft altitudes.

These predictions have repeatedly been verified by actual in-flight radiation measurements.

There exist tools that predict the radiation dose during solar cosmic ray events.

For polar routes, the solar cosmic ray dose will be ~the same as the galactic cosmic ray dose at 40,000 ft

Rule of thumb: polar sea-level neutron monitor increase % / 10 = ~μSv per hour @ 40,000 ft

There are unresolved issues regarding the health risk from exposure to low levels of ionizing radiation.

The radiation risk problem will not be resolved for decades!

VERTICAL CUTOFF RIGIDITIES (GV)

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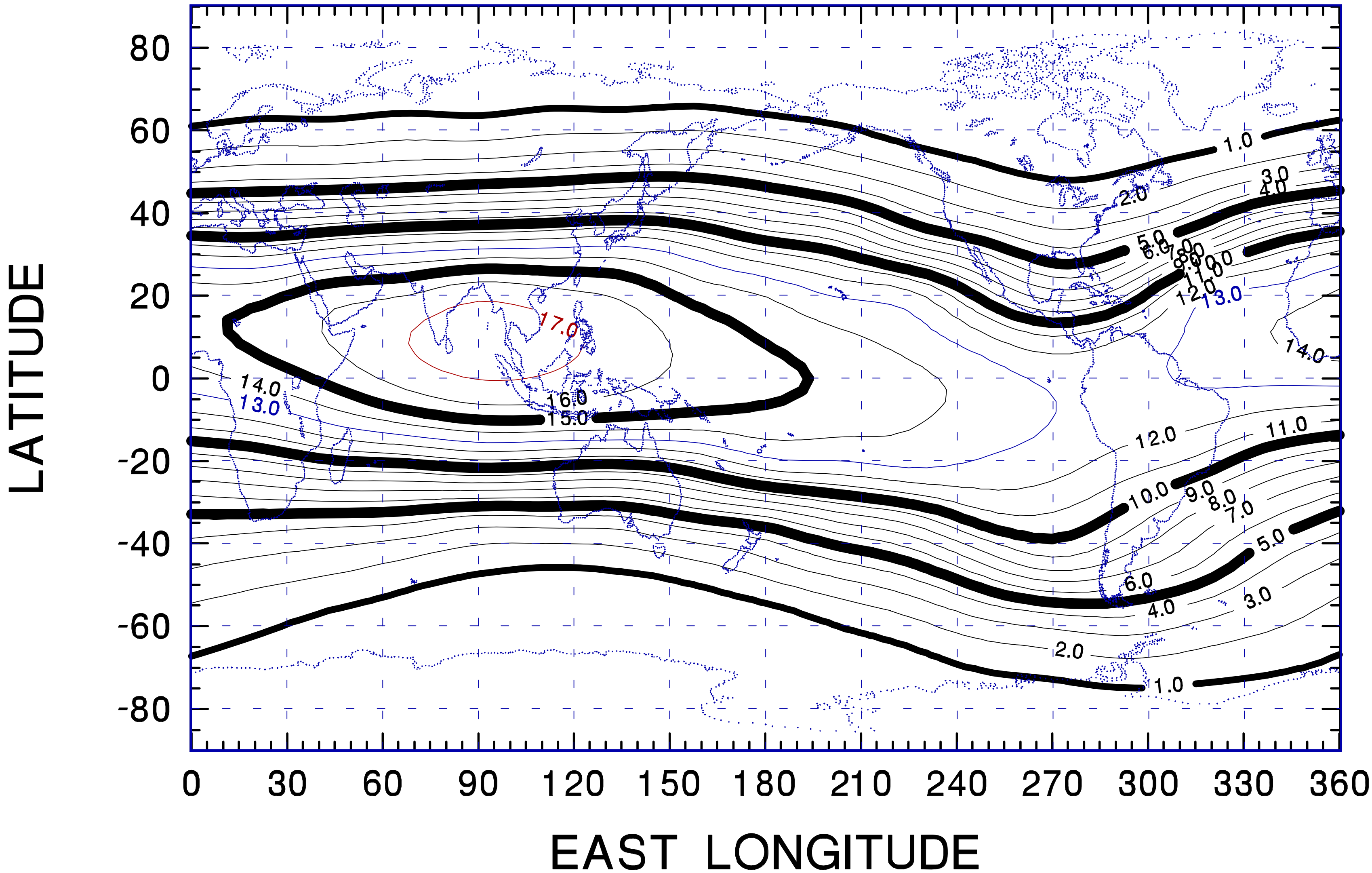
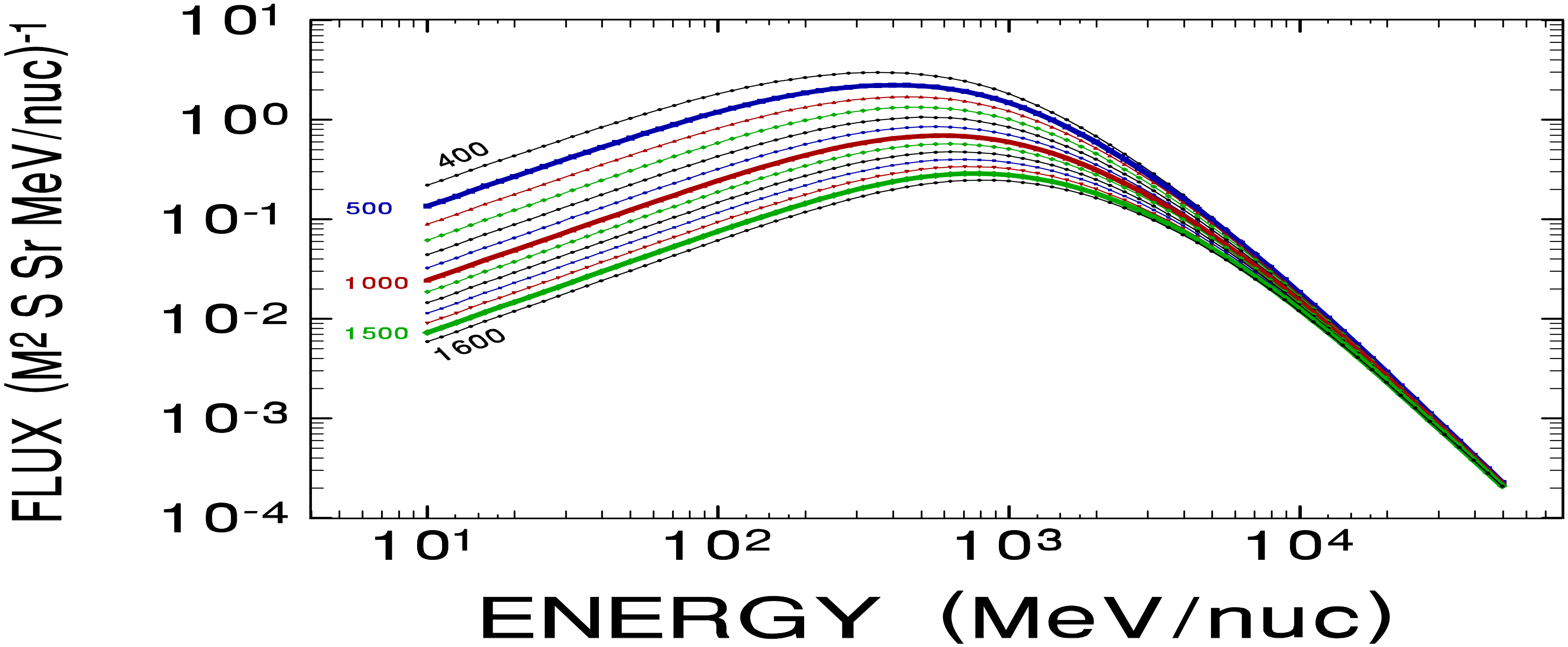
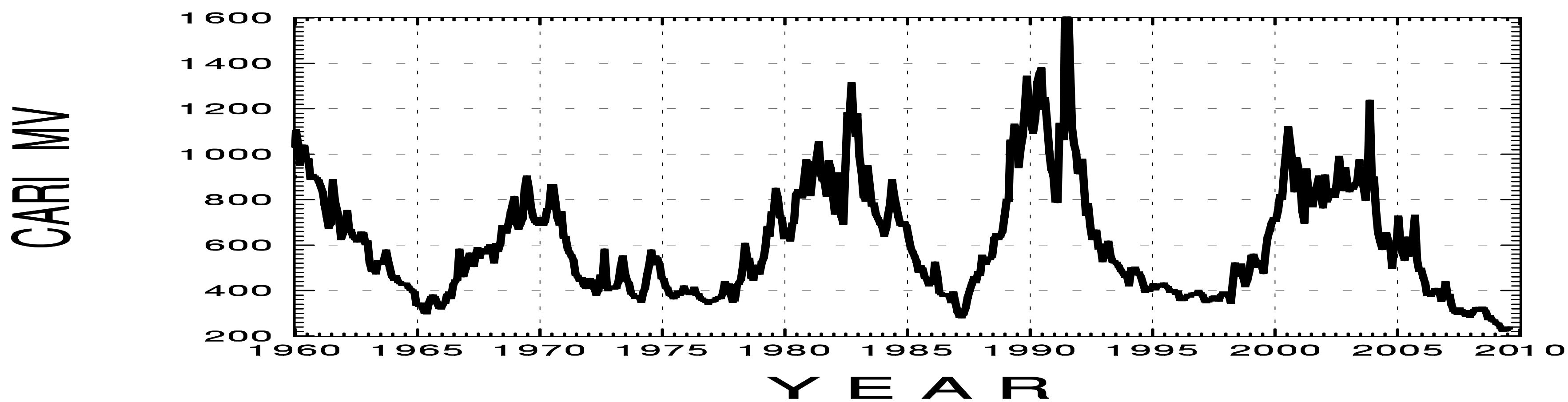


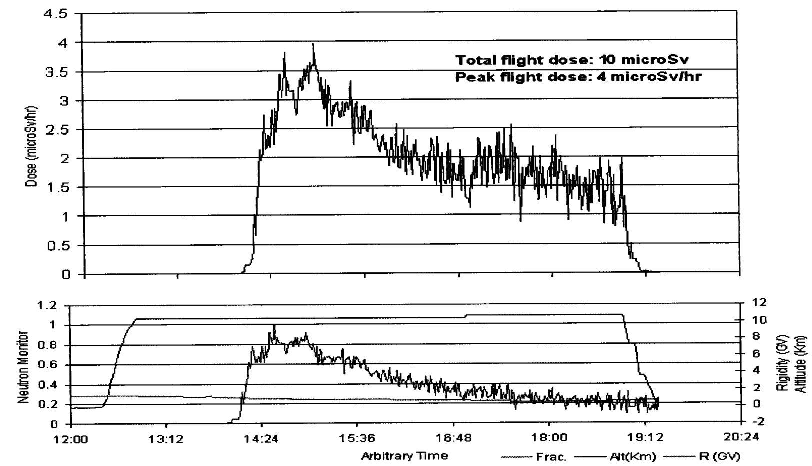
COSMIC RAY PROTON SPECTRUM
MODULATION Phi = 400 to 1600



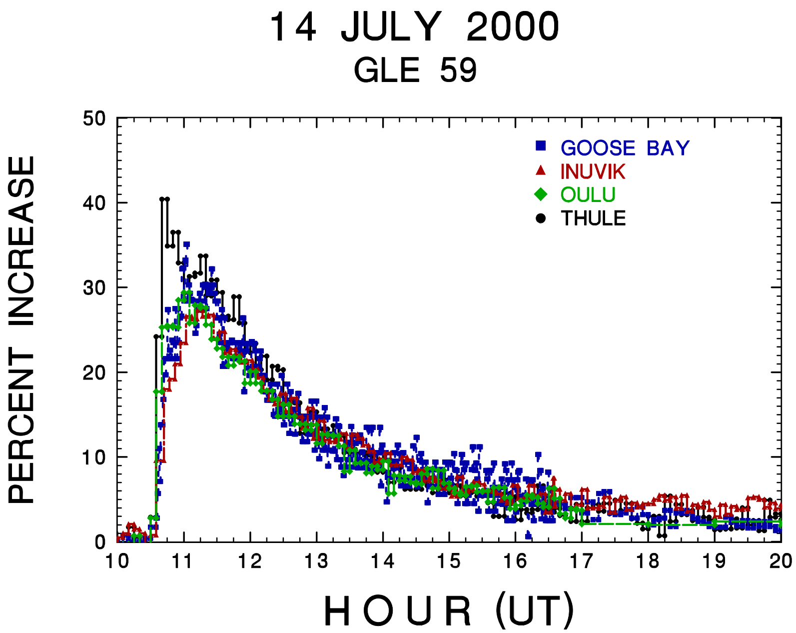
COSMIC RAY MODULATION PARAMETER



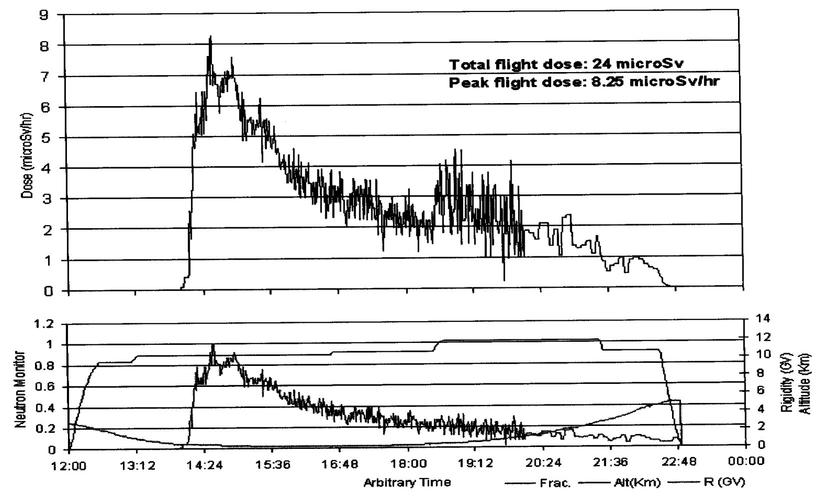
Computed maximum radiation dose rates due to solar cosmic rays for GLE 59 (14 July 2000) along England – USA flight paths.
(Source Clucas et al., ASR **36**, 1657, 2005)



LHR – JFJ

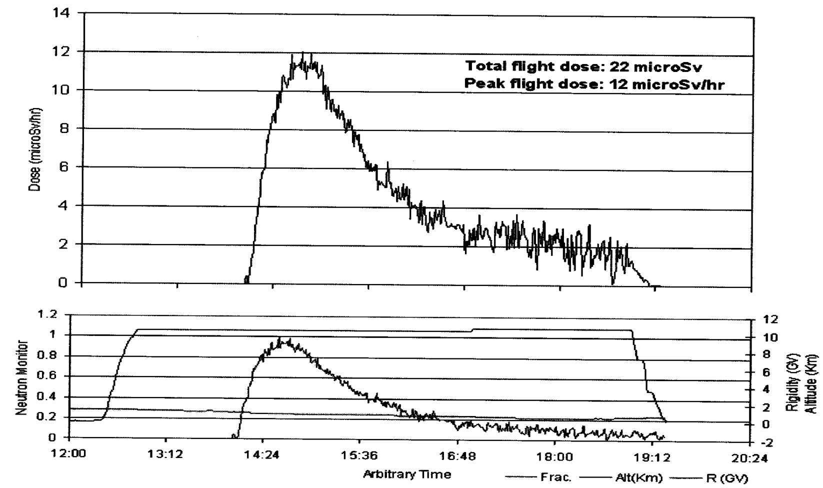


Increase observed by N. polar neutron monitors

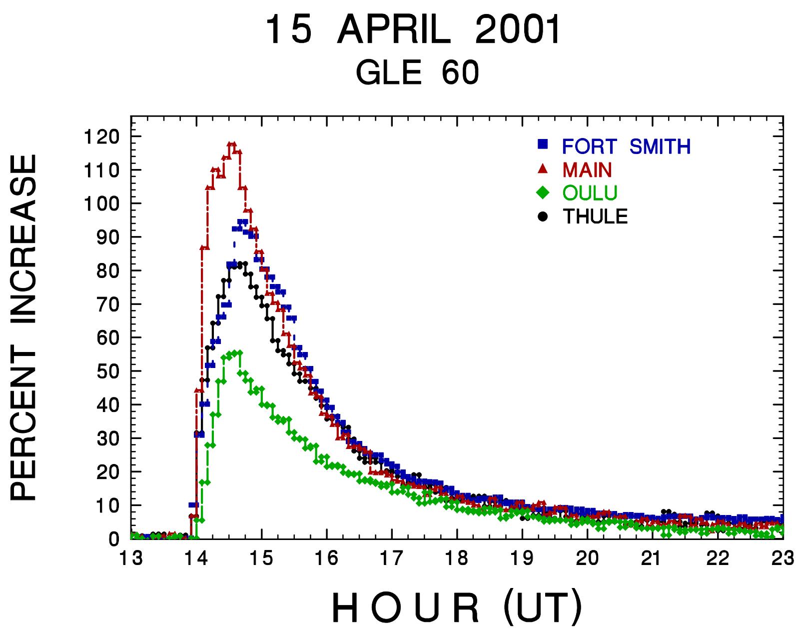


LHR – LAX

Computed maximum radiation dose rates due to solar cosmic rays for GLE 60 (15 April 2001) along England – USA flight paths.
(Source Clucas et al., ASR **36**, 1657, 2005)



LHR – JFK



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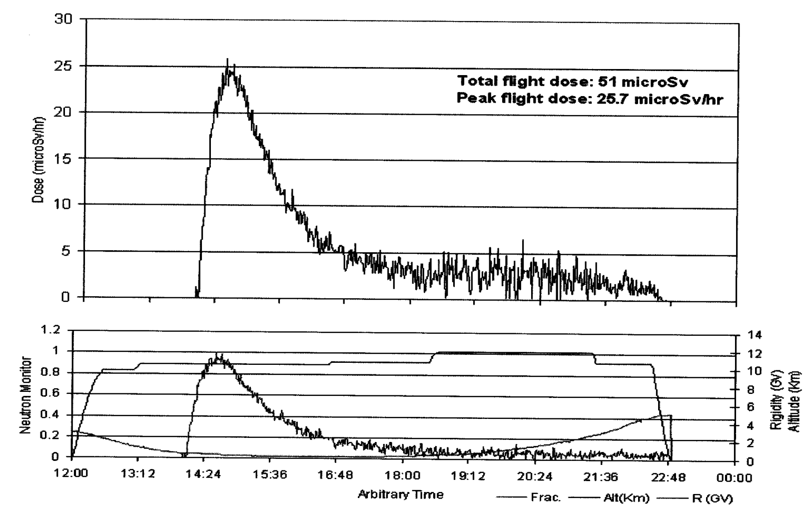

LHR – LAX