

Radiation Health Risks to Commercial Space Flight (Suborbital and Orbital)

Presented at:

15th Annual Commercial Space Transportation Conference

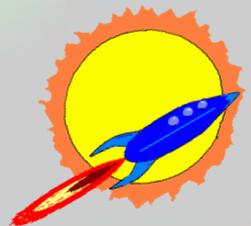
Feb 15, 2012

By

Dr. Ronald E. Turner

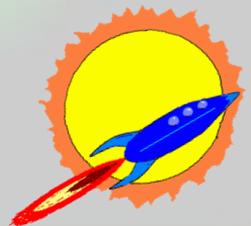
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Outline

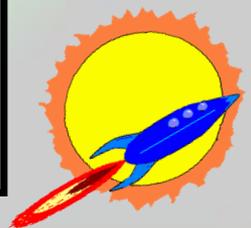
- **Introduction**
- **Health Risks from Radiation**
- **Suborbital Flight**
- **Orbital Flight**
- **Conclusions**



Introduction

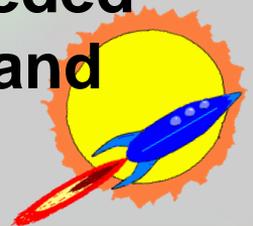
- **Space Weather impacts**
 - **Communications**
 - **Avionics**
 - **Orbital lifetime**
 - **Human health**
- **This presentation focuses on the human health risks from radiation exposure in**
 - **Suborbital Space Flight *and***
 - **Orbital Space Flight**

With adequate consideration, preparation and appropriate caution, none of these impacts need be severe or mission limiting.



Caveats

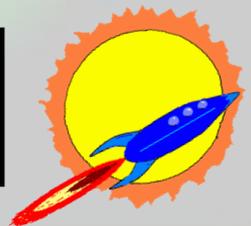
- **Crew vs. Passenger**
 - This briefing focuses on the impact to *passengers* of commercial space transportation
 - Single flight
 - Population average
 - Informed consent
 - *Crew* may need special consideration as they may be subject to substantially more exposure
 - Multiple suborbital flights
 - Possibly more and longer duration orbital flights
- **Pregnancy**
 - Additional protection/constraints may be needed to protect fetus/unborn child of passengers and crew



Space Radiation Health Risks

- **Four categories of health risk:**
 - ***Carcinogenesis (morbidity and mortality risk)***
 - ***Chronic & Degenerative Tissue Risks***
 - *Cataracts, heart-disease, immune system, etc.*
 - ***Acute Radiation Risks—sickness or death***
 - ***Acute and Late Central Nervous System (CNS) risks***
 - *Immediate or late functional changes*
- **Differences in biological damage of heavy nuclei in space compared to x-rays limits Earth-based radiation data on health effects for space applications**

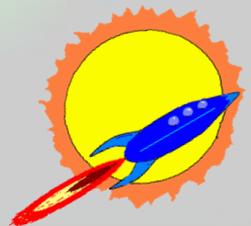
For suborbital and short-duration orbital missions, the most significant (though still minor) risk is **cancer**



Space Radiation Induced Cancers

- There is no doubt that exposure to *significant* levels of radiation will increase the *probability* of cancer
- There is substantial (*orders of magnitude*) uncertainty in quantifying the details
- Sources of uncertainty include, but are not limited to:
 - Lack of understanding of the causative chain of events from exposure to cancer
 - Difference between the space environment and terrestrial exposure experience
 - Lack of relevant data

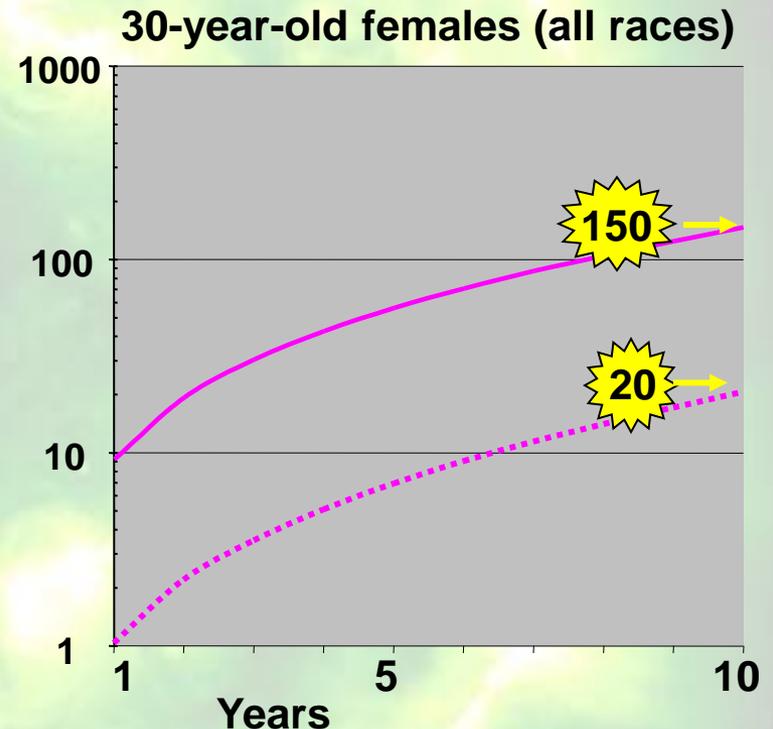
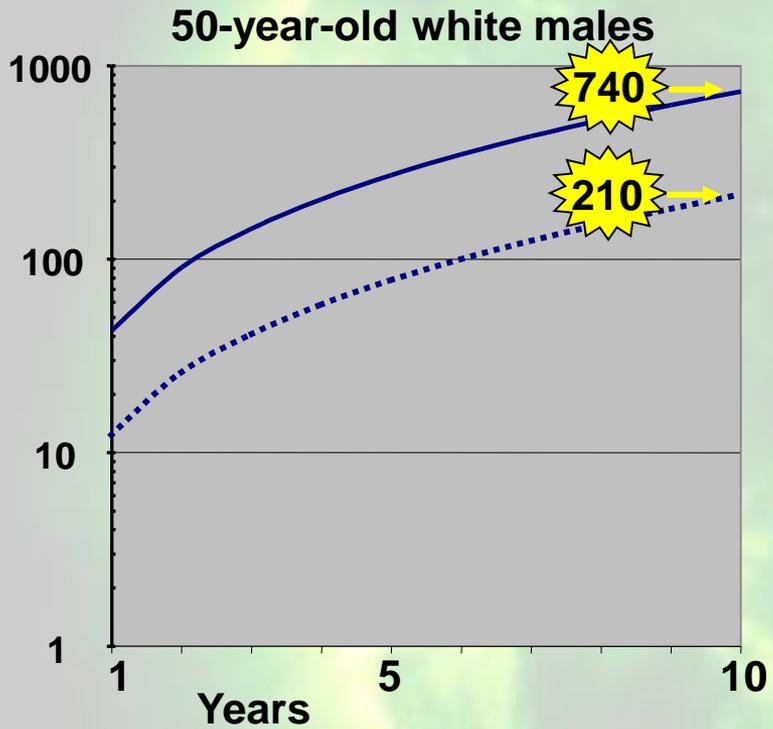
*A better understanding of **space radiation health effects** is needed to reduce uncertainties*



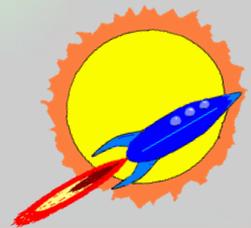
Cumulative Cancer Incidence, Deaths (US – 10,000 Starting Population)

Cumulative Cancer Incidence
 Cumulative Cancer Deaths

DevCan: Probability of Developing or Dying of Cancer Software, Version 6.1.1; Statistical Research and Applications Branch, National Cancer Institute, 2005. <http://srab.cancer.gov/devcan>



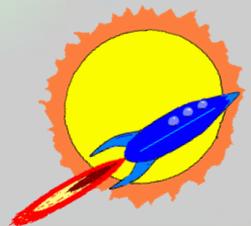
For context only... These rates are without radiation exposure



Public Exposure to Radiation

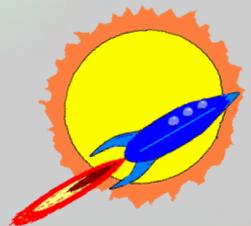
- We are all constantly exposed to radiation, in a variety of forms and to varying degrees
- On average a person is exposed to less than **5 mSv** per year, typically about **3.6 mSv**
 - Some workers are exposed to higher levels of radiation than the general public. On average those workers with significant occupational exposure are exposed to **an additional one to three mSv per year**
- Of the typical public exposure, over eighty percent is from natural sources
 - About half (55 percent) of the total exposure is from radon
 - About eight percent is from cosmic radiation reaching the Earth's surface (about 0.26 mSv/year, doubling with each 2 km altitude above sea level)
 - Another eight percent is from naturally occurring radionuclides
 - Eleven percent is from radionuclides in one's body, both as a natural component of tissue and as natural components of the food one eats
- Another eighteen percent of the typical 3-4 mSv annual exposure is from man-made sources

Public exposure to radiation is described in a report by the National Council on Radiation Protection and Measurements [*Report No. 160 - Ionizing Radiation Exposure of the Population of the United States (2009)*]



Exposure From Commercial Aircraft Flight

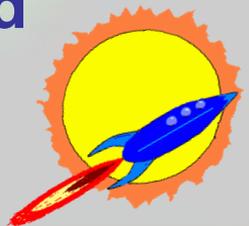
- Exposure from commercial air transportation is included within the estimate for man-made exposures
 - Typical cruising altitudes for commercial flights vary from 25,000 to 40,000 ft (8,000 to 12,000 meters)
 - Dose equivalent rates at these altitudes vary from three to seven μSv per hour. For comparison, sea level exposure rate is only 0.03 μSv per hour
 - A five-hour cross country commercial air trip would total on the order of **25 μSv** or 0.025 mSv, well below the 0.26 mSv annual sea level cosmic ray exposure



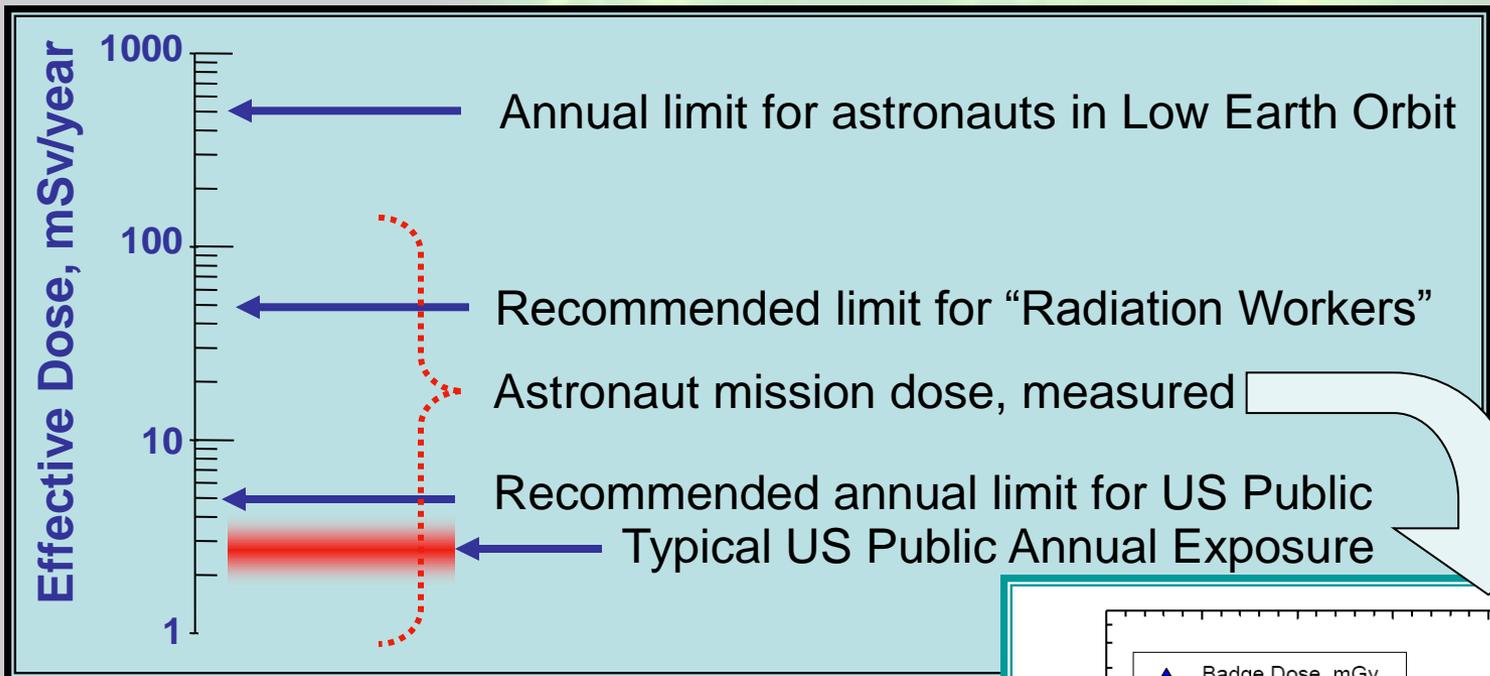
Conventional Wisdom / Rule of Thumb

- Twenty cSv (equivalent dose) exposure increases the probability of a fatal cancer by one percent¹
- This Rule of Thumb has many caveats
 - Is over-generalized
 - May not apply to very low dose rates
 - May not apply to space radiation
- NASA does not use this paradigm, using instead a confidence interval approach incorporating a large body of data sources and uncertainties
 - NASA is also looking beyond cancer impacts and is considering acute, chronic, and degenerative impacts
- However, for a first approximation, the Rule of Thumb is likely conservative and will be a good indicator for impacts

1: <http://www.physics.isu.edu/radinf/risk.htm>

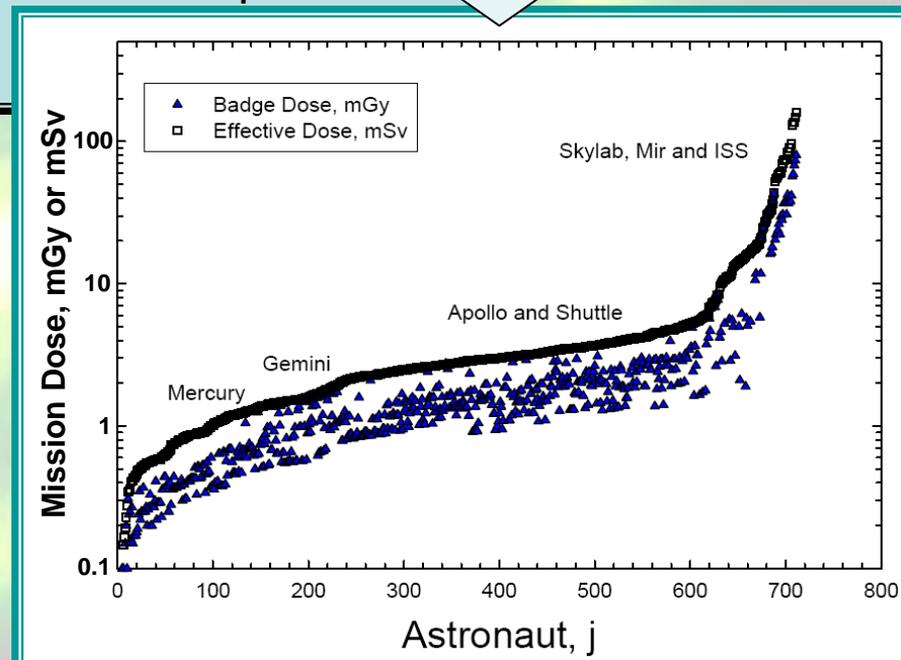


Space Radiation Exposure Put in Context



Other examples:

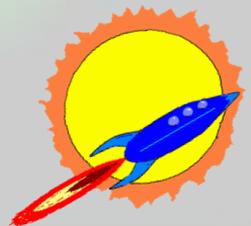
Chest x-ray	.05 to .2 mSv
Cross-country round trip	.05 mSv
High-altitude dose rate	.02 mSv/hour
Dose rates on orbit	.1 to 1 mSv/day



Source for figure in lower right panel: Cucinotta, F.A., Badhwar, G.D., Saganti, P.B., Schimmerling, W., Wilson, J.W., Peterson, L.E., and Dicello, J.F., *Space radiation cancer risk projections for exploration missions: Uncertainty reduction and mitigation*, NASA TP 2002-210777, 2002.

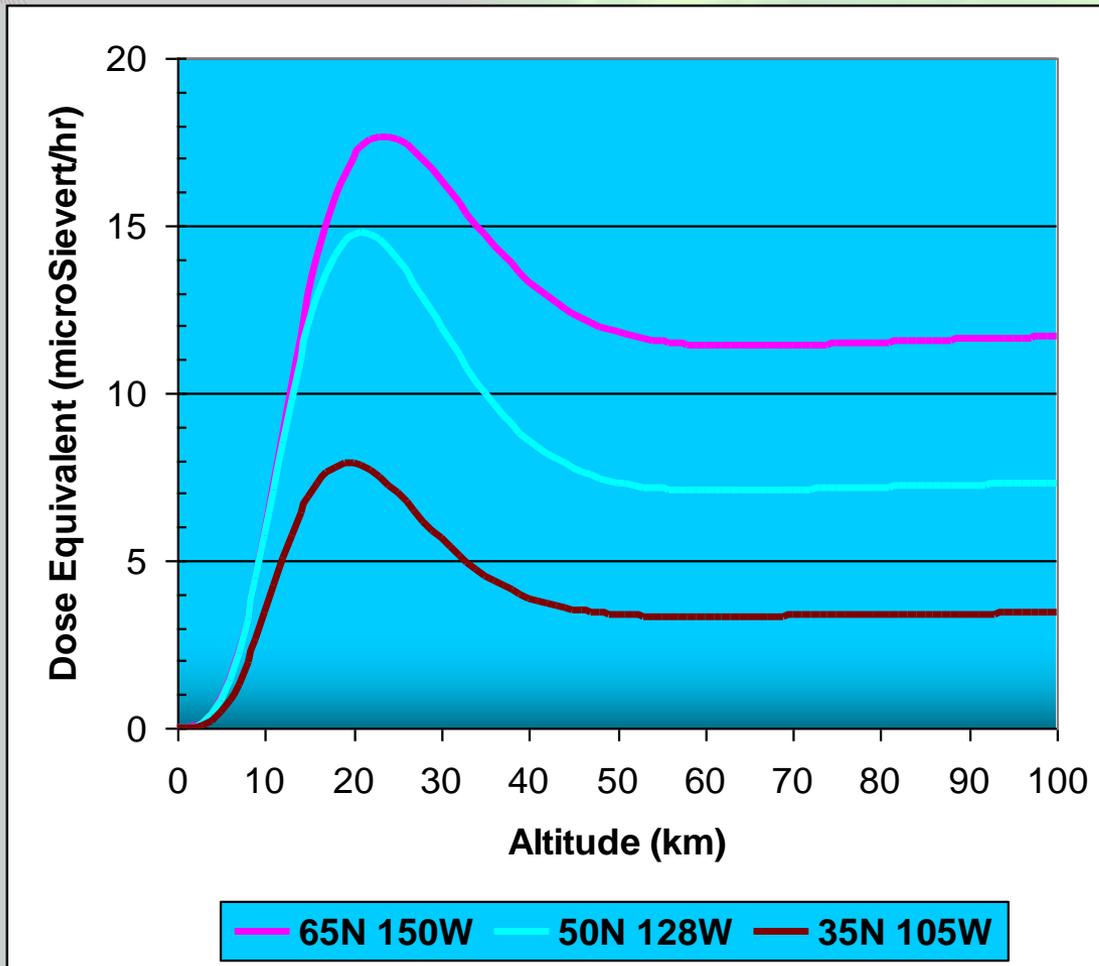
Suborbital Commercial Space Flight

- Suborbital Impacts are based on “*Space Weather Biological and System Effects for Suborbital Flights*”
 - Aerospace produced four representative suborbital flight profiles
 - The QinetiQ radiation model “QARM” was used to model dose equivalent versus altitude at three latitudes representing nominal launch locations



QARM Dose Equivalent vs Altitude

(In tissue, no additional shielding)



Conditions:

Solar Minimum
(Maximum GCR)
Geomagnetically quiet
(Kp ~ 2)

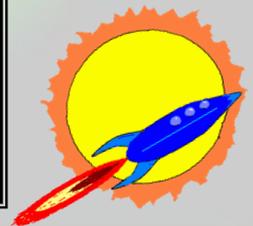
Caveat:

Geomagnetically active conditions near Solar Minimum could increase dose rate by 50 percent

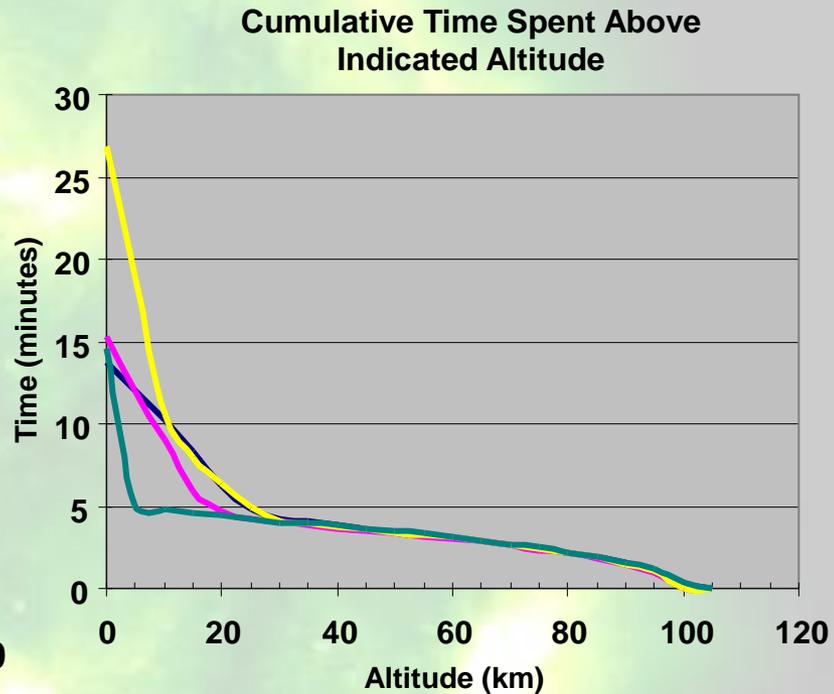
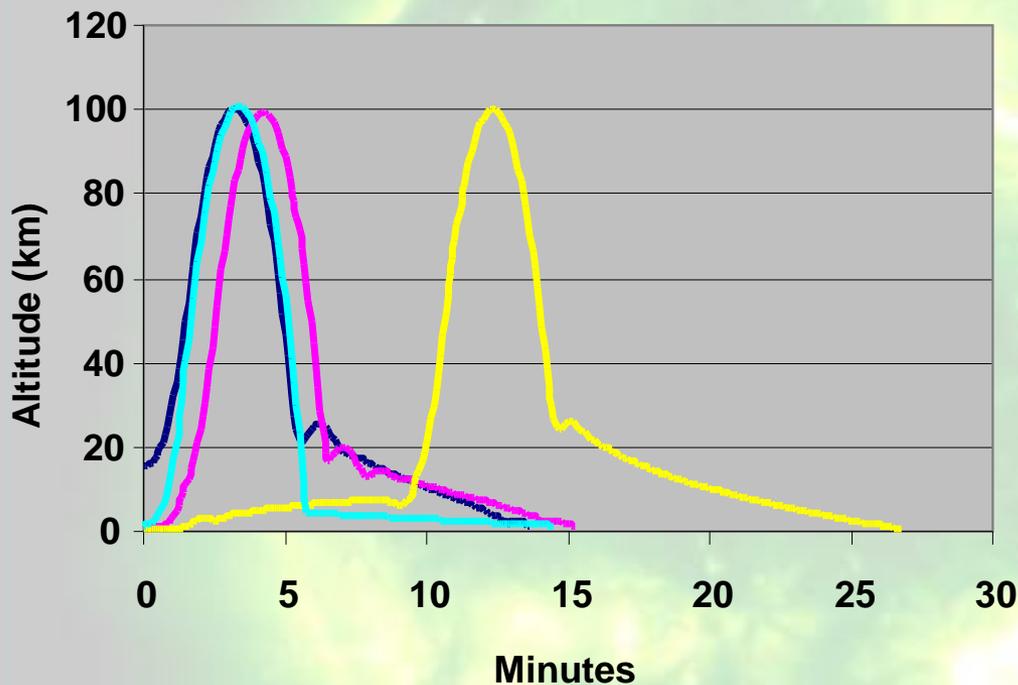
Solar Maximum has reduced GCR but potential Solar Storms with peak dose rates **at high latitudes** more than two orders of magnitude higher than the rates shown here

QinetiQ Atmospheric Radiation Model (QARM) is a comprehensive atmospheric radiation model constructed using Monte Carlo simulations of particle transport through the atmosphere. It uses atmospheric response matrices containing the response of the atmosphere to incident particles on the upper atmosphere.

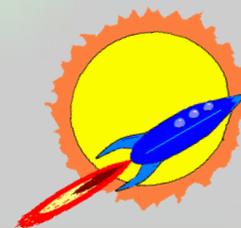
<http://geoshaft.space.qinetiq.com/qarm/index.jsp?URL=start.jsp>



Four Representative Flight Profiles



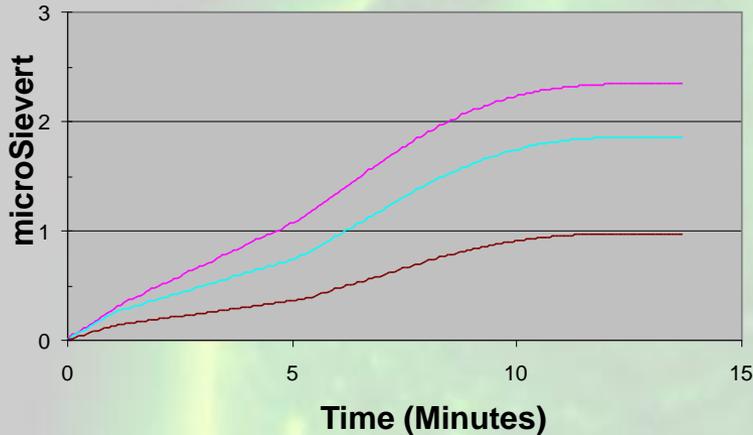
— Airlaunch, NM Spiral	— All Rocket, NM Spiral
— HTHL Jet and Rocket	— VTVL NM East



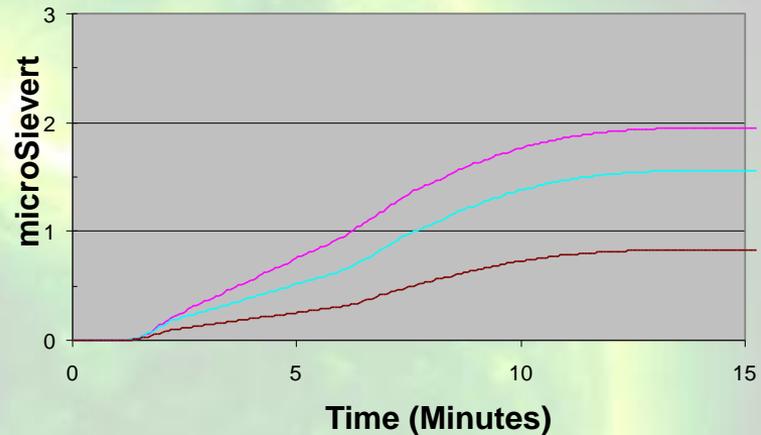
Cumulative Dose Equivalent

Various Suborbital Trajectories, Launch Sites

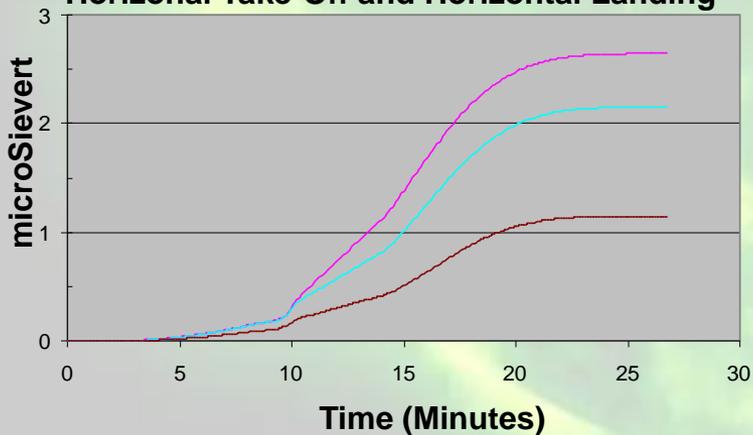
Airlaunch, New Mexico Spiral



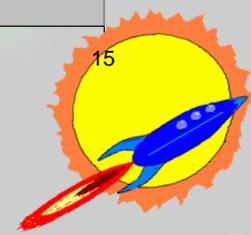
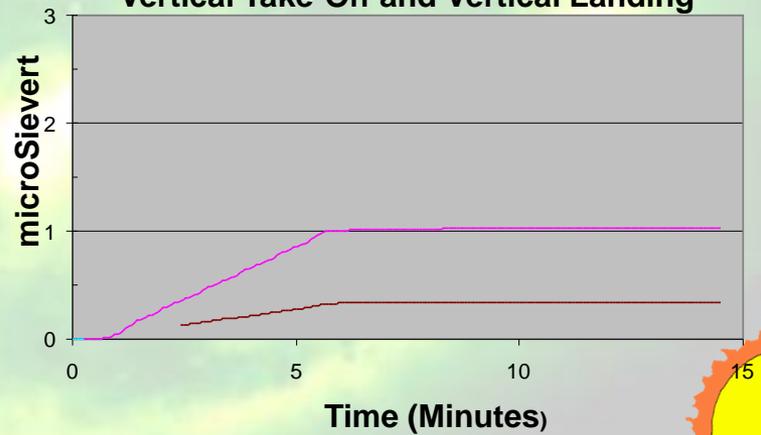
All Rocket, New Mexico Spiral



Horizontal Take-Off and Horizontal Landing



Vertical Take-Off and Vertical Landing



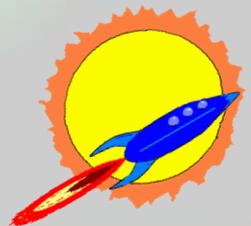
Cumulative Dose Equivalent Various Suborbital Trajectories, Launch Sites

	Cumulative Dose Equivalent (microSievert)		
	65N 150W	50N 128W	35N 105W
Airlaunch, NM Spiral	2.35	1.86	0.98
All Rocket, NM Spiral	1.95	1.56	0.84
HTHL Jet and Rocket	2.64	2.15	1.15
VTVL Jet and Rocket	1.03	0.71	0.34

Radiation exposure ranges from **0.34 to 2.64 microSv (μSv)**

By way of comparison, recall that a cross country commercial flight nominal exposure is on the order of **25 microSv (μSv)**

Radiation exposure on a sub-orbital flight is substantially less than cross-country commercial airline flight



Excess Fatal Cancers

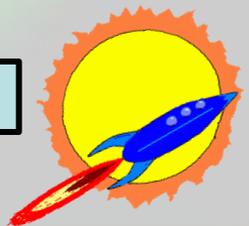
Single Flight, Per 10,000 tourists

	Excess Fatal Cancers (Per 10,000)		
	65N 150W	50N 128W	35N 105W
Airlaunch, NM Spiral	.0017	.00093	.00049
All Rocket, NM Spiral	.00098	.00078	.00042
HTHL Jet and Rocket	.0013	.0011	.00057
VTVL Jet and Rocket	.00052	.00035	.00017

Rate is from:

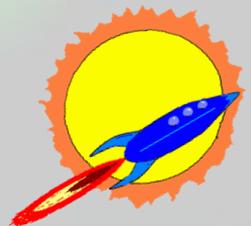
Exposure in microSievert
 x .05 percent per centiSievert / 100
 x 10,000 flights
 x 1/10,000 microSievert/centiSievert

Fewer than 1 excess Cancer Fatality per Million single flights



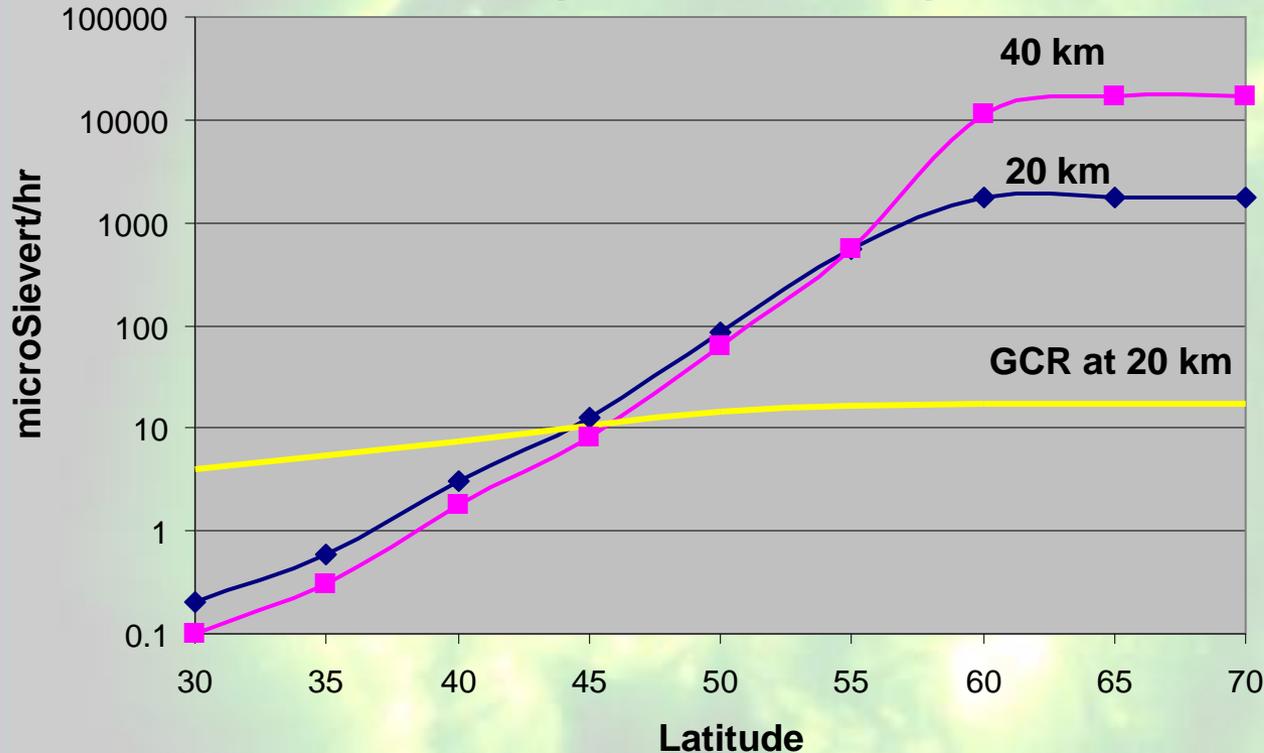
Impact of Solar Storms

- **Solar storm exposure can be orders of magnitude greater than experienced during quiet geomagnetic and solar conditions**
 - Solar storms cannot be reliably forecast days or even hours in advance
 - NOAA Space Weather Prediction Center issues alerts when a storm may be imminent and when one is underway
 - While solar storms cannot be forecast days or even hours in advance, they can be reliably detected at onset
- **QARM was used to estimate impact at high latitudes for two representative large storms (29 Sept 89 and 24 Oct 89)**
- **There is a rapid drop in exposure as latitude decreases from 65 N to 50 N and below**
- **Exposure during an event would be very sensitive to**
 - Total exposure duration
 - Timing relative to event onset and peak
 - Geomagnetic conditions
 - Flight profile
 - Shielding provided by vehicle



SPE Exposure vs. Latitude

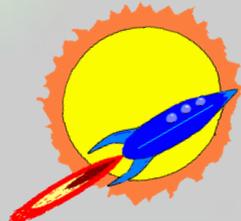
Dose Equivalent for 29 Sept 1989



Dose equivalent from solar storms increases exponentially with latitude, up to a peak above 60 degrees

Shown for comparison is Solar Minimum GCR at 20 km (near peak)

For SubOrbital Flights, Solar Storm exposure is below background GCR for latitudes less than 45 degrees (Seattle, Washington, is at 47.5 degrees North)



Impact of Solar Storms

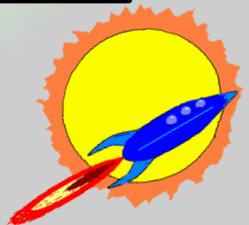
65N 150 W Under Various Suborbital Trajectories

	Cumulative Dose Equivalent (microSievert)		
	Quiet GCR	29 Sep 89	24 Oct 89
Airlaunch, NM Spiral	2.35	1287	263
All Rocket, NM Spiral	1.95	1157	239
HTHL Jet and Rocket	2.64	1269	259
VTVL Jet and Rocket	1.03	1103	230

Radiation exposure could be two to three orders of magnitude above nominal, but only if:

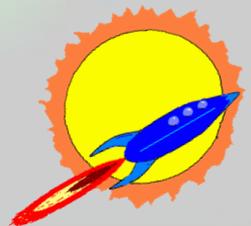
- From high latitude site (55 to 65 degrees)
- Launched during peak of storm

Total exposure is still limited to only **0.2 to 1 mSv**

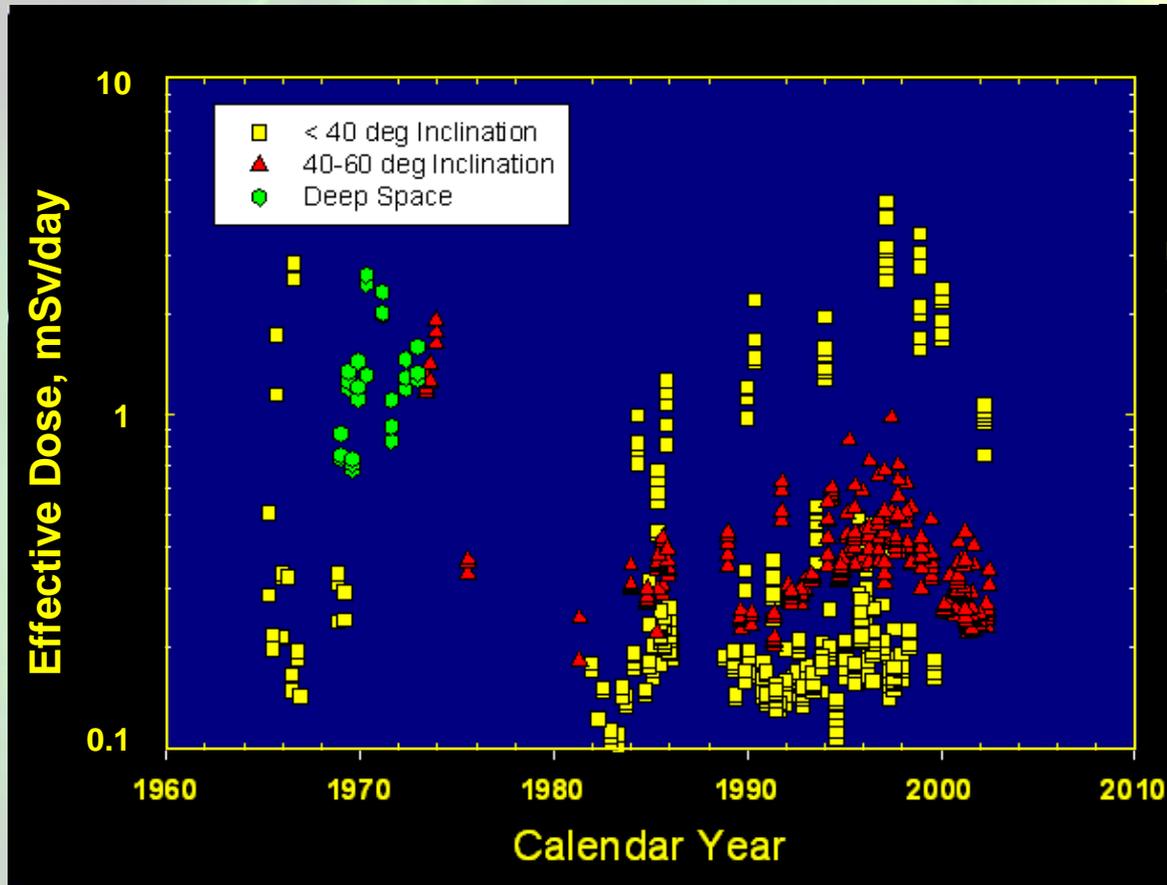


Orbital Commercial Space Flight

- **Orbital flight will significantly increase radiation exposure**
 - More intense environment
 - Longer exposure time
- **Exposure is within the US astronaut experience base**
 - Early Shuttle flights were generally low inclination (23 degrees), lasting one to two weeks
 - ISS is high inclination, medium altitude, Typically three to six months duration



US Astronaut Daily Exposure Rate History



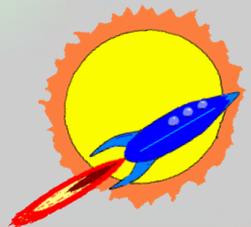
Source: F. A. Cucinotta, H. Wu, M.R. Shavers, and K. George, "Radiation Dosimetry and BioPhysical Models of Space Radiation Effects," *Gravitational and Space Biology Bulletin* 16(2) June 2003



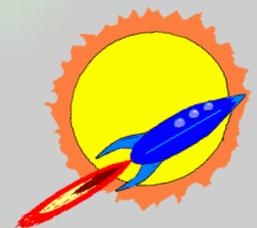
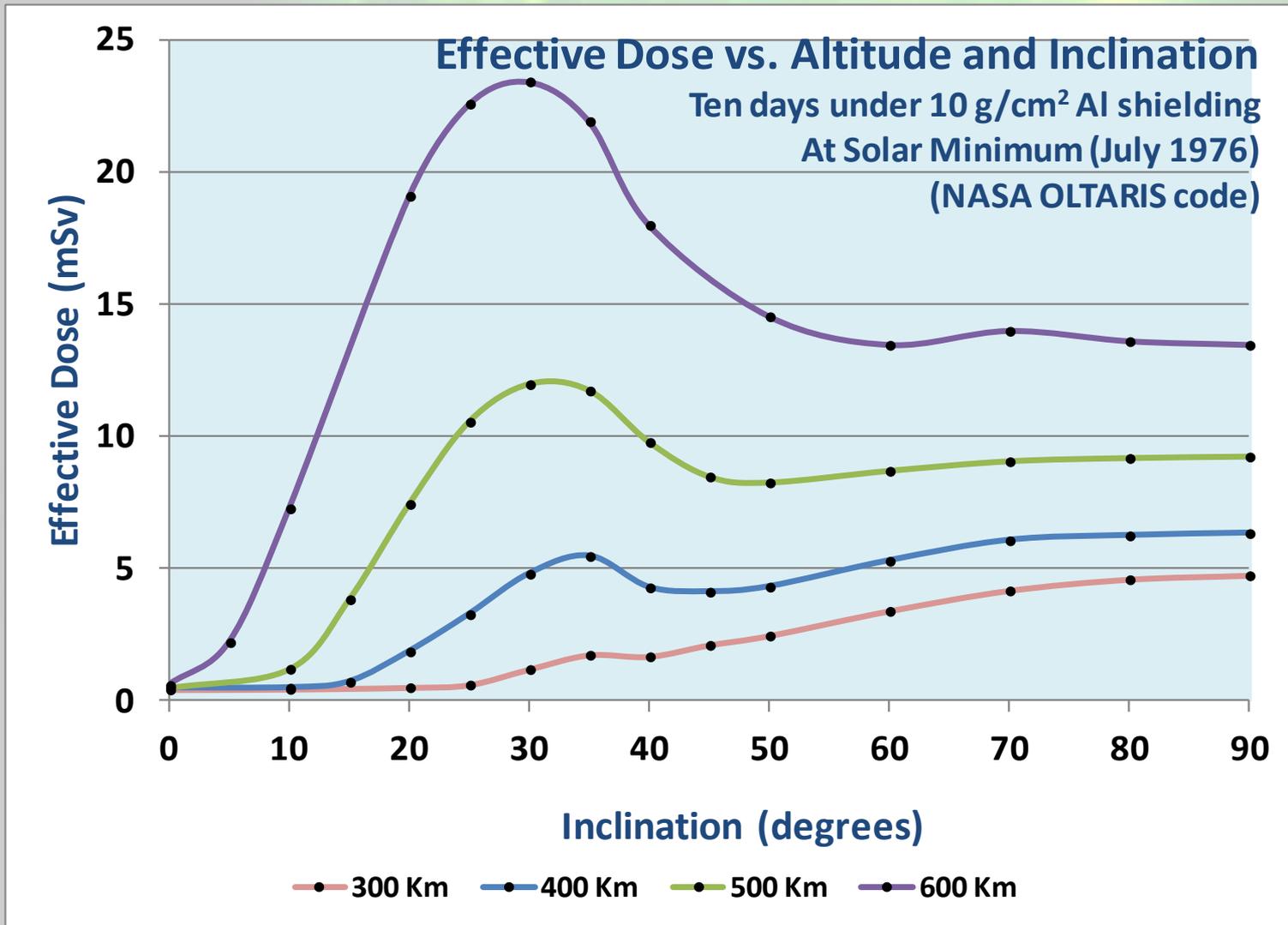
Orbital Exposure Variability

Exposure on orbit varies with

- **Altitude**
- **Inclination**
- **Solar Cycle**
- **Solar Activity**
- **Vehicle Shielding**
- **Vehicle Orientation**
- **Location Within Vehicle**

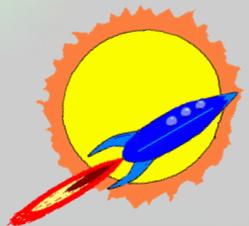


Radiation Exposure vs Altitude and Latitude



Radiation Exposure vs Altitude and Latitude

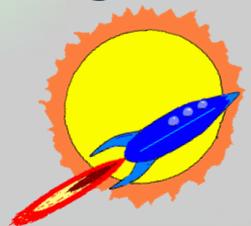
- **Low Altitude, Low Inclination:**
 - **3 - 5 mSv** is about equal to the typical annual US population exposure of 3 - 5 mSv
 - Corresponds to 1-3 excess cancer fatalities per 10,000 tourists
- **High Altitude, High Inclination:**
 - **15 - 25 mSv** is about 5 times the typical annual US population exposure
 - Corresponds to 8-12 excess cancer fatalities per 10,000 tourists



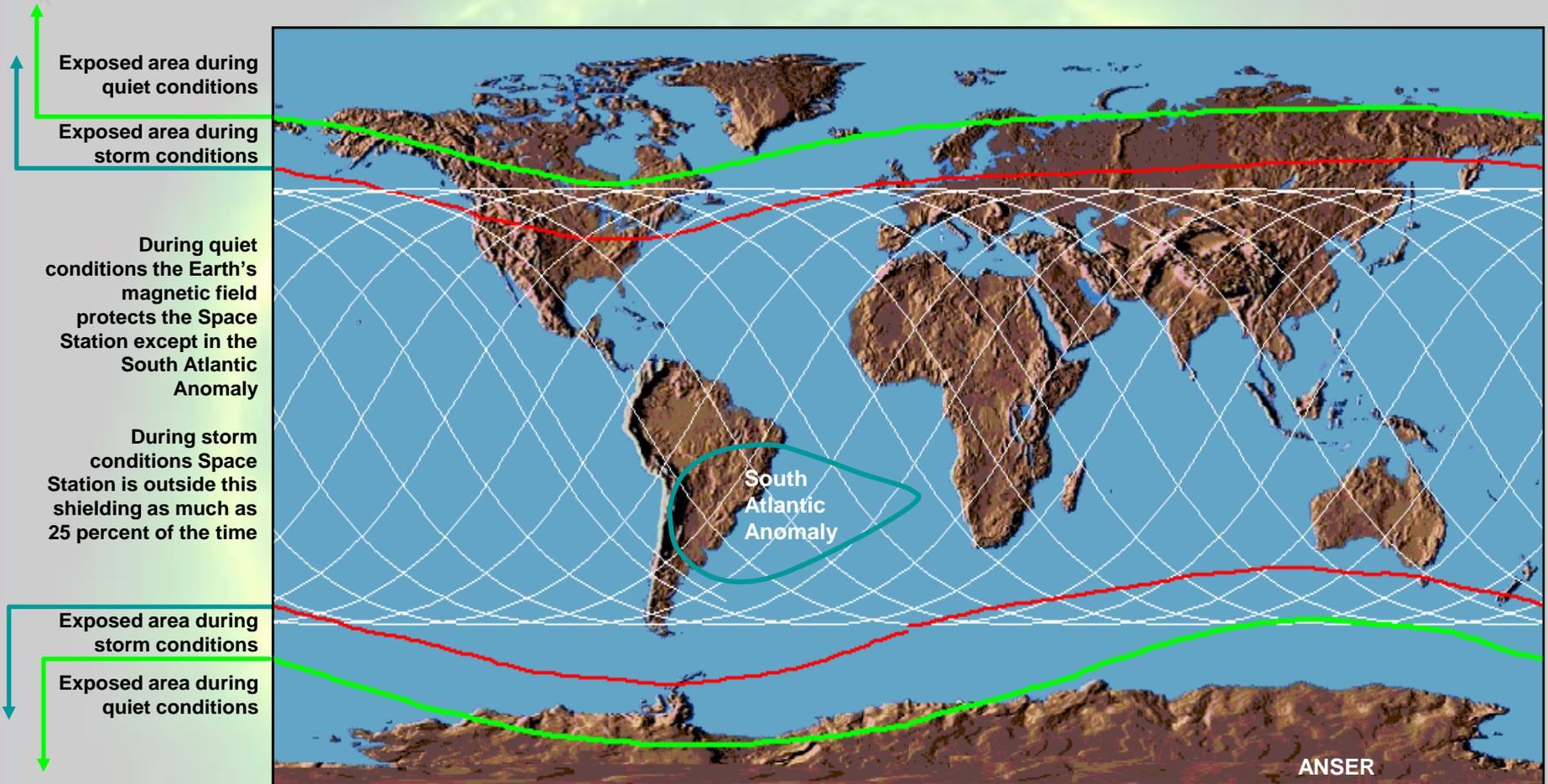
Solar Particle Events

Impact on Orbital Flights

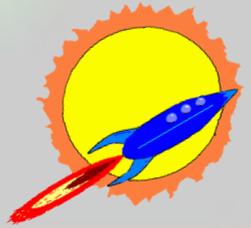
- **Solar Particle Events will increase exposure, but not substantially**
 - **Except during possible EVAs**
- **The Earth's magnetic field provides shielding except inside the auroral oval**
 - **Only a few high inclination orbits per day penetrate the open region**
 - **The additional exposure is generally less than ten minutes per orbit**
 - **Background GCR actually decreases during large SPEs**



ISS Exposure To Solar Storms



During solar storm conditions, the International Space Station is outside shielded area less than 25 percent of the time (51.6 degree inclination). Lower Inclination orbits are substantially protected from SPEs



Space Weather Needs¹

- An inexpensive and reliable way to receive information concerning current space weather conditions, including “go/no-go” safety instructions just prior to “launch”
- A full characterization of the nominal space environment for their normative flight profile, including nominal radiation dosages that passengers can expect, given the particular vehicle properties, as well as any predictable variances from those norms
- The ability to track actual radiation dosages obtained over a number of flights to verify the theoretical calculation of radiation exposure
- Monitoring devices that, to the extent possible, can provide accurate post-flight data as to each passenger’s individual exposure during the flight

¹NOAA SEC’s Space Weather Week in April 2006, *Jim Dunstan*

