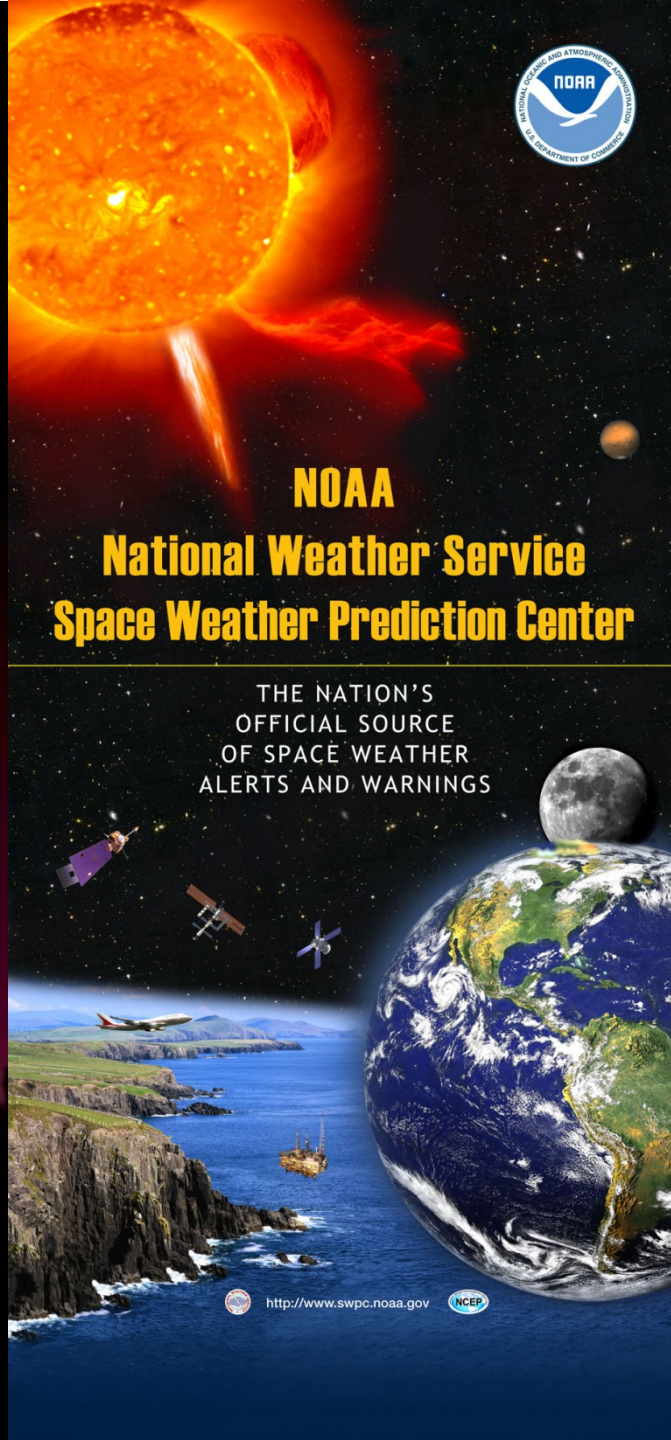
Aviation Radiation Exposure – A Primer…

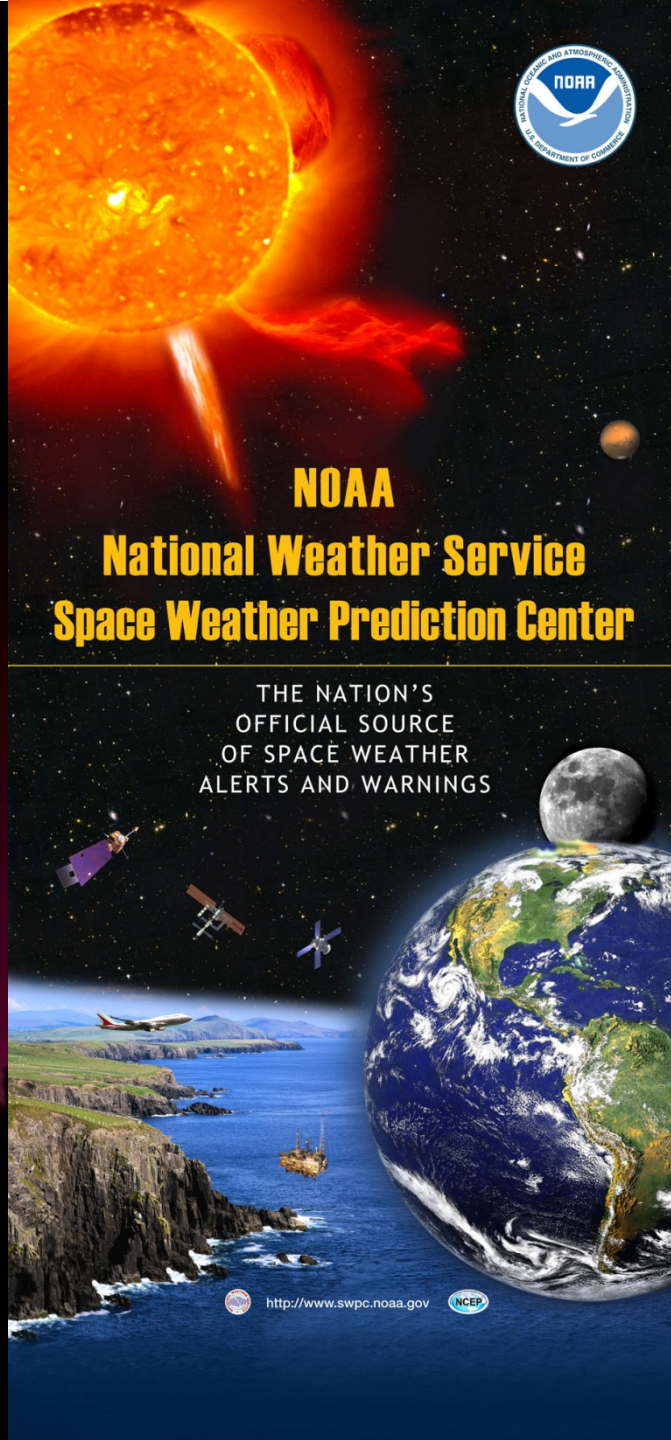
Bob Rutledge
NOAA Space Weather Prediction Center
Boulder, Colorado
May 17th-20th, 2016



Cross Polar Working Group – Montreal, Canada

Outline

- Source Terms
- Areas Affected
- Practical Example
- Understanding Exposure
- Modeling Progress



Source Terms – Background Radiation

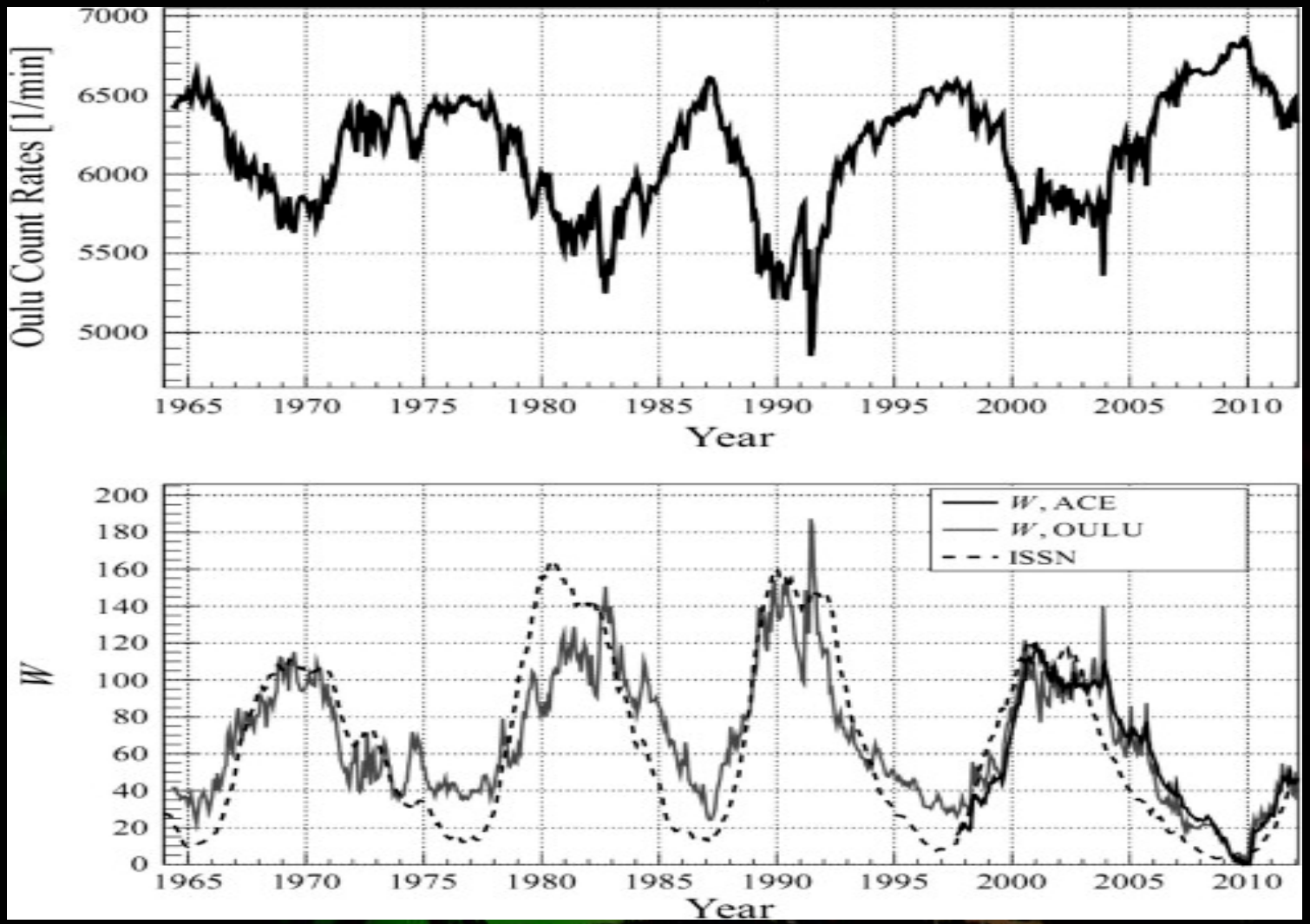
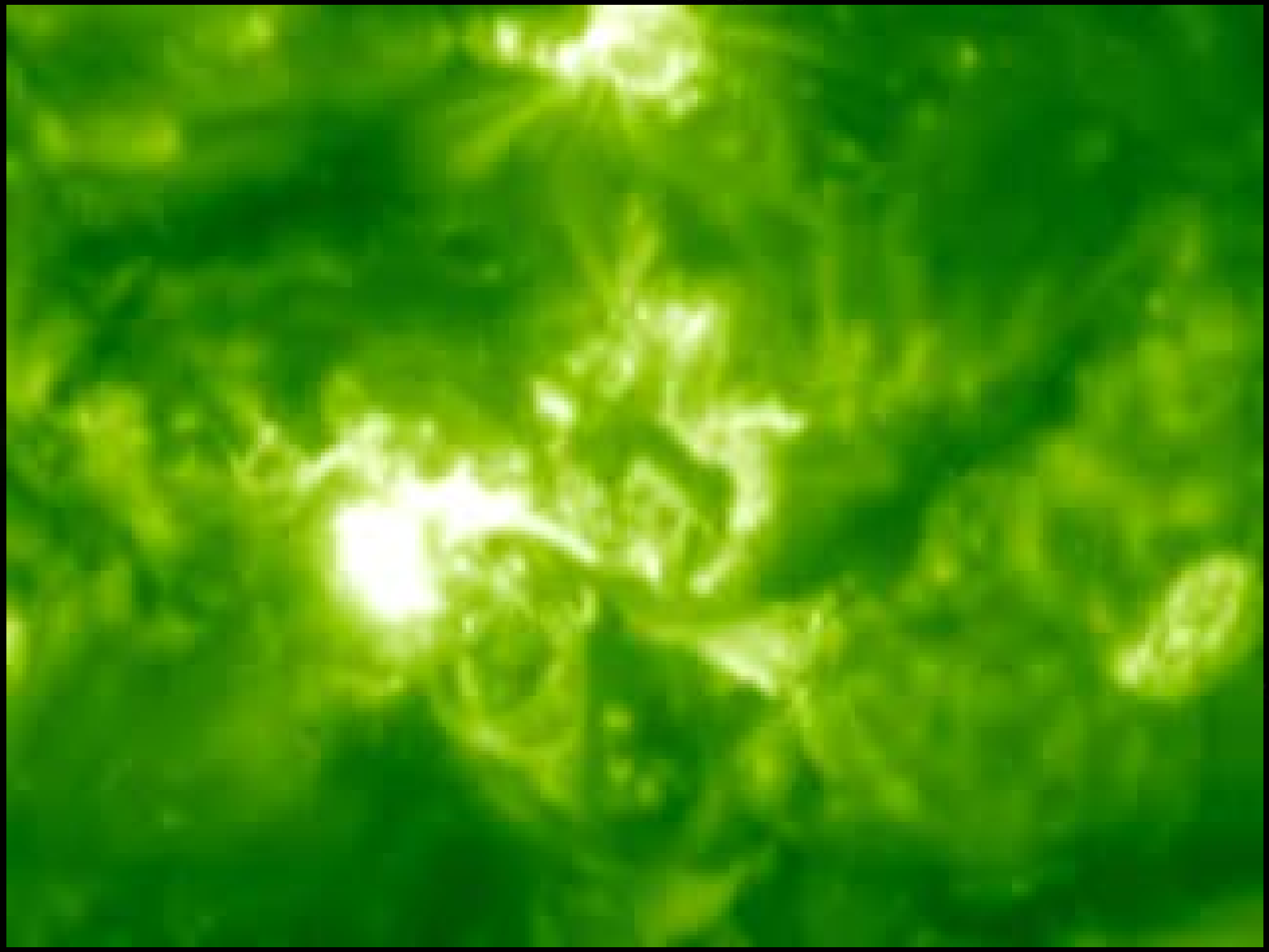
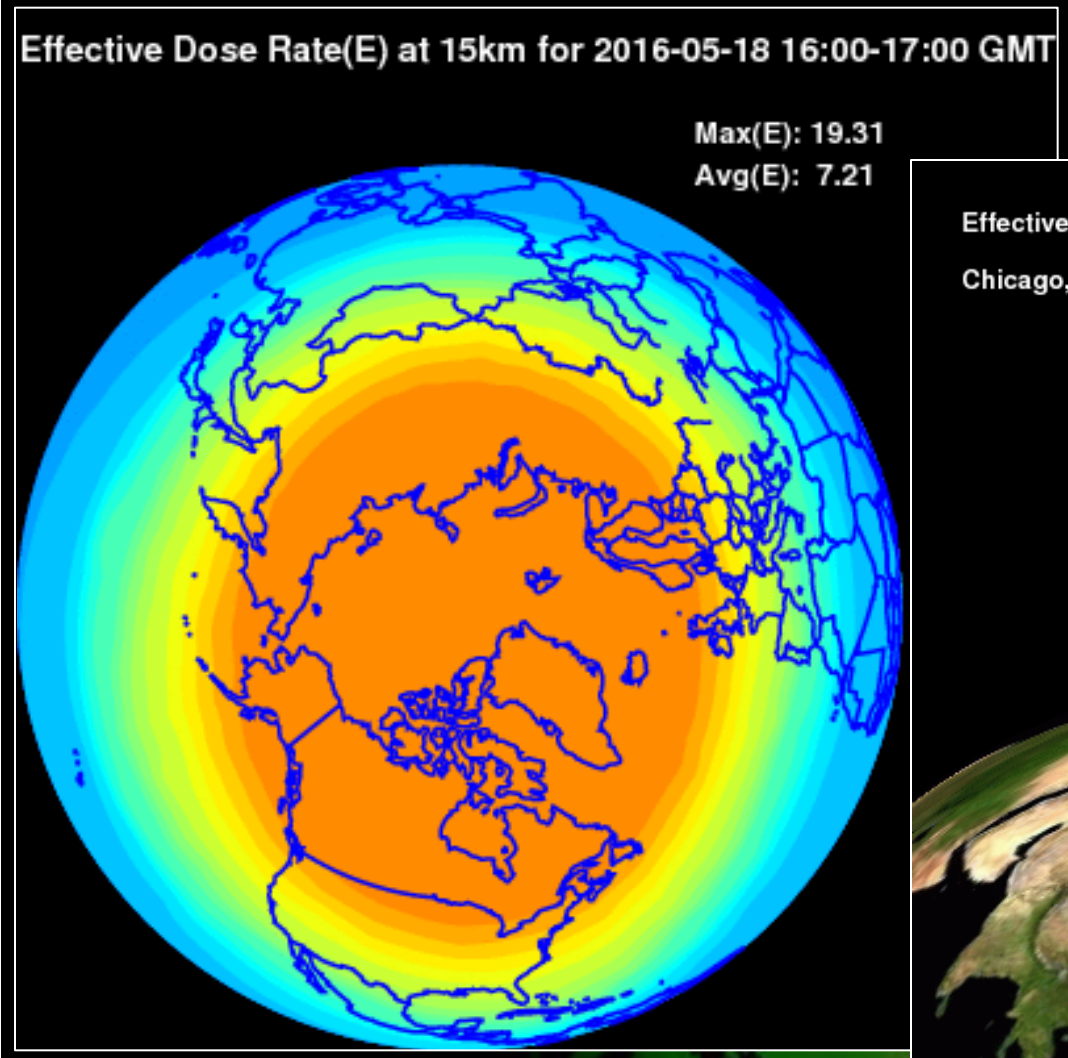


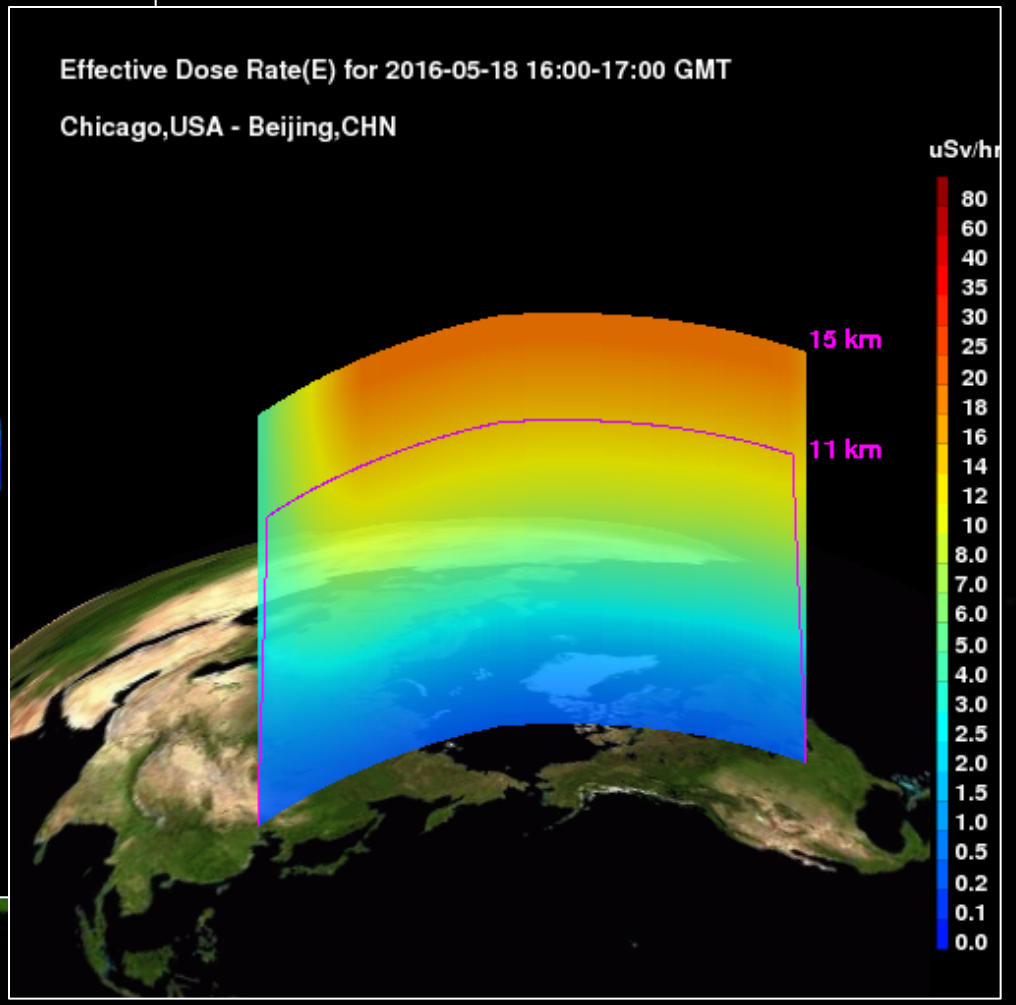
Image credit Matthia, et al., A Ready-to-Use Galactic Cosmic Ray Model (2013)

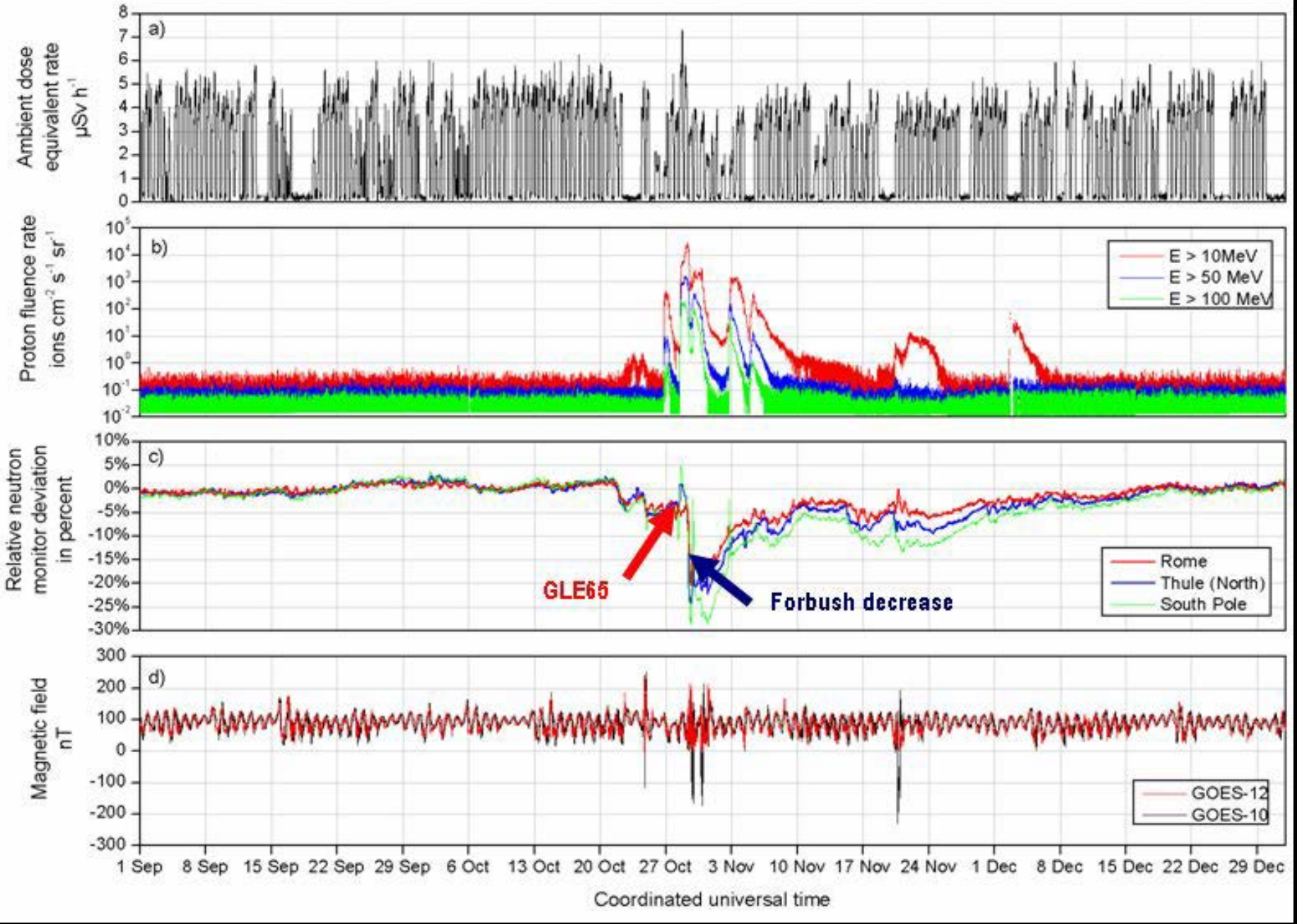
Source Terms – Space Weather



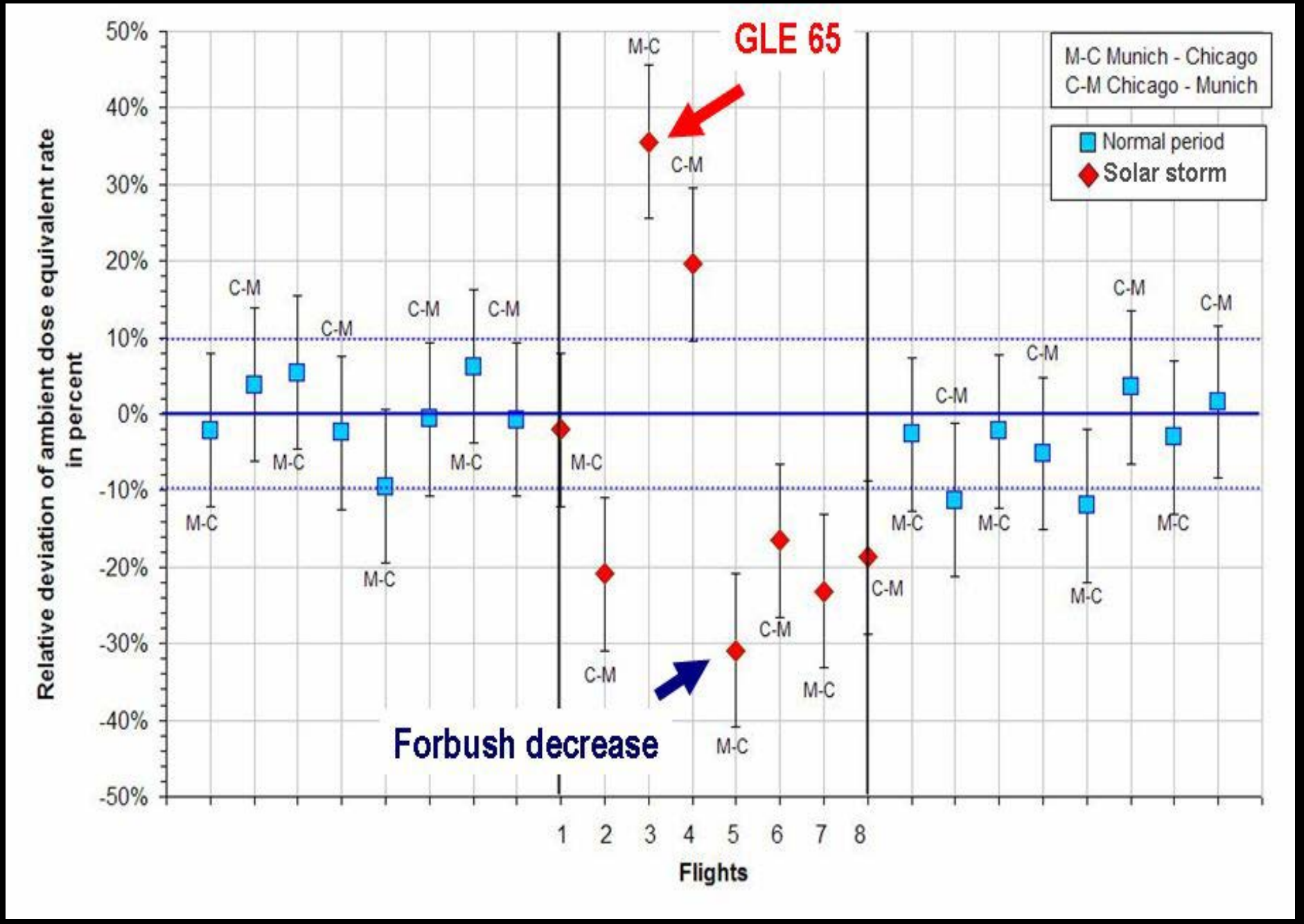
Areas Affected







Peter Beck, et al. 2005



Peter Beck, et al. 2005

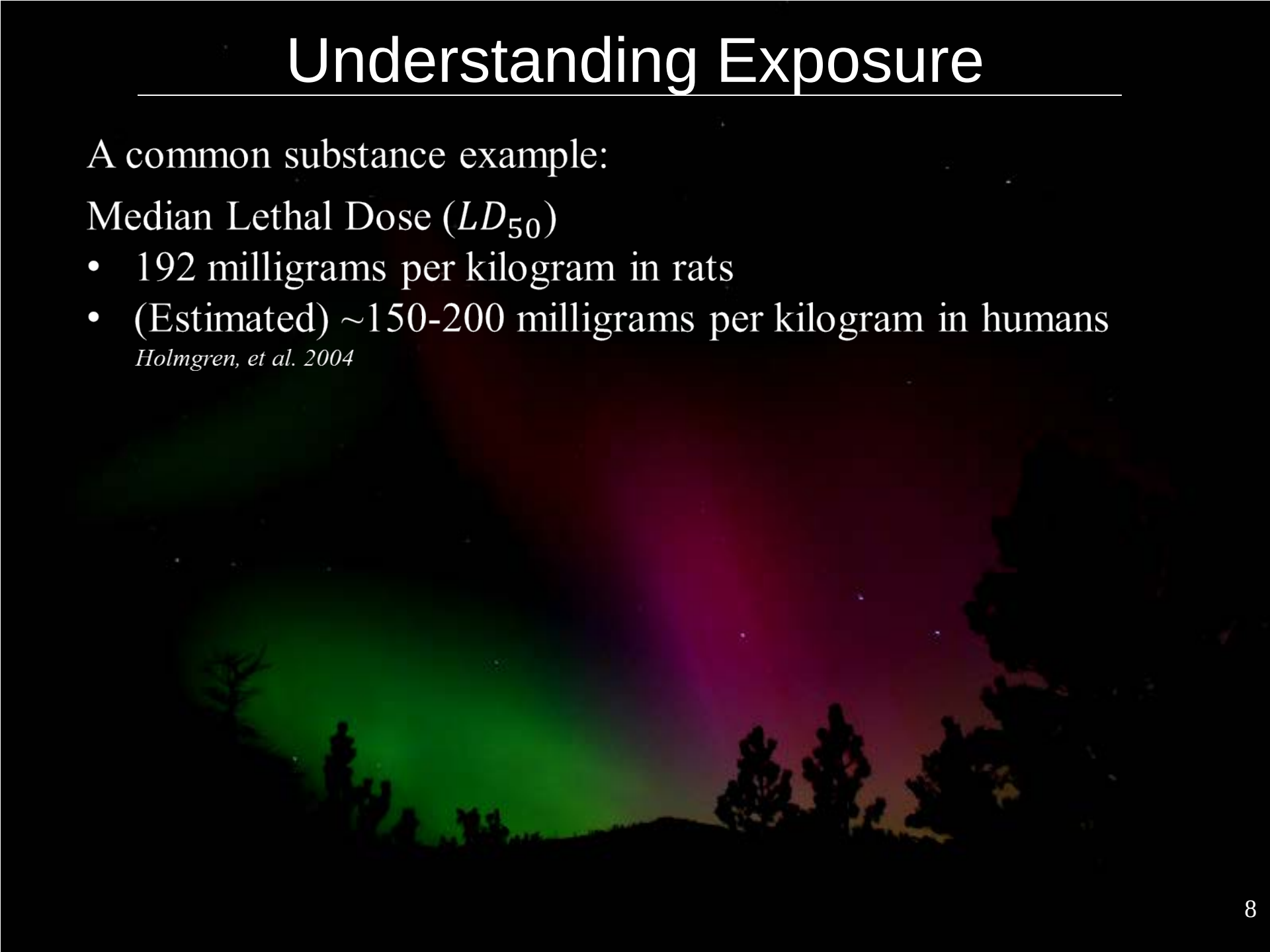
Understanding Exposure

A common substance example:

Median Lethal Dose (LD_{50})

- 192 milligrams per kilogram in rats
- (Estimated) ~150-200 milligrams per kilogram in humans

Holmgren, et al. 2004



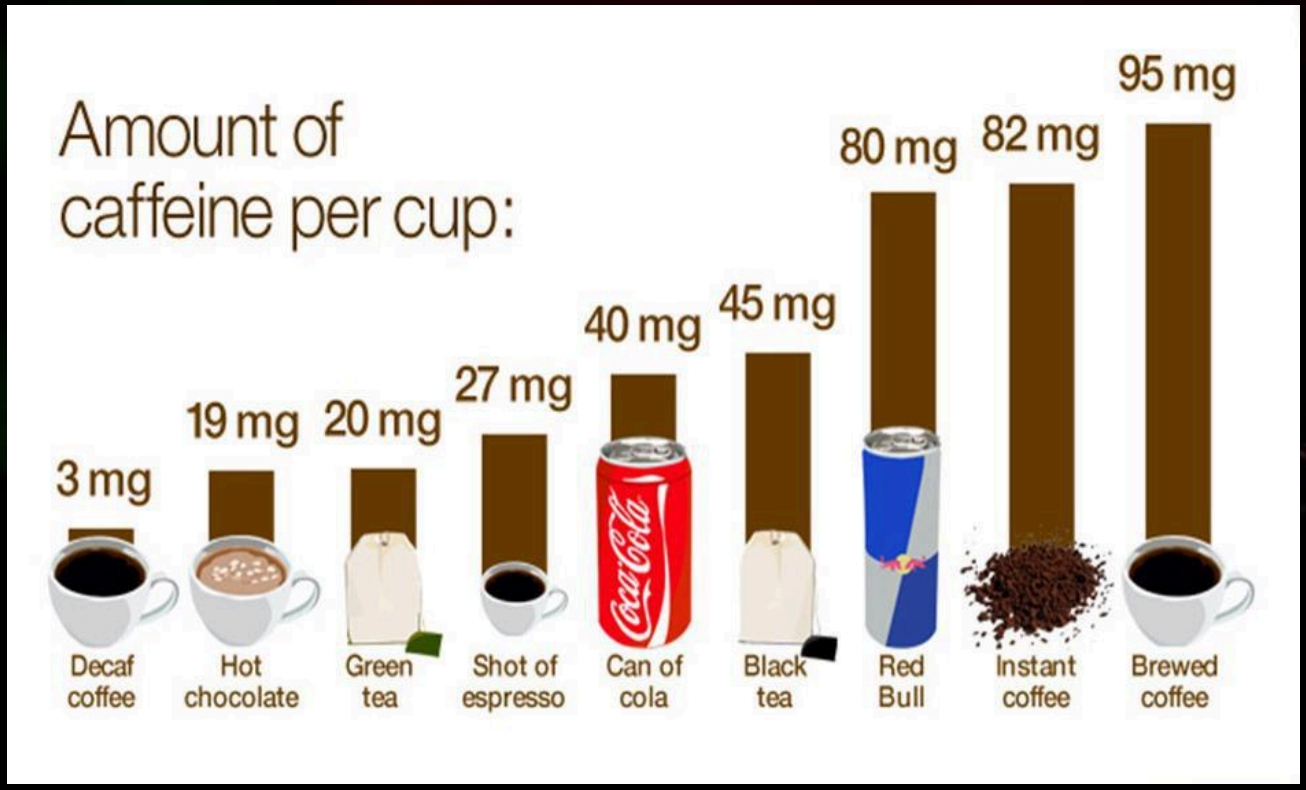
Understanding Exposure

A common substance example: CAFFEINE

Median Lethal Dose (LD_{50})

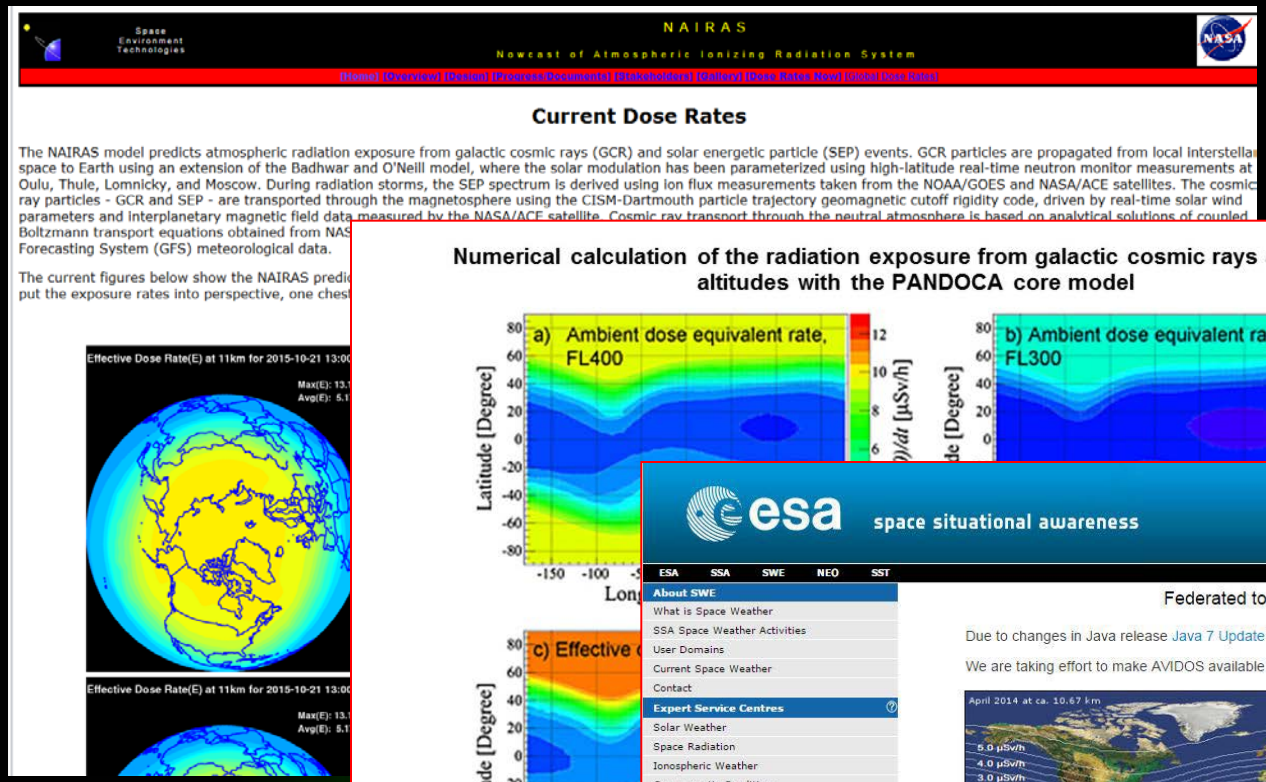
- 192 milligrams per kilogram in rats
- (Estimated) ~150-200 milligrams per kilogram in humans

Holmgren, et al. 2004



http://www.mountainstrongdenver.com/caffeine-and-sports-performance/

Aviation Radiation Modeling Examples



NAIRAS

PANDOCA

AVIDOS

Many efforts… Who's doing it well? They don't all agree.

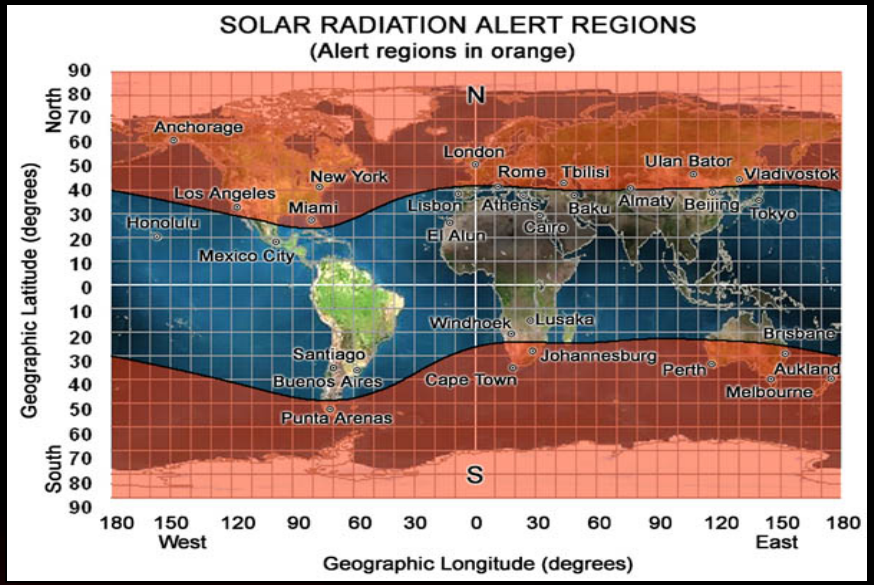
NOAA Space Weather Prediction Center

Boulder, Colorado

www.spaceweather.gov


BACKUP SLIDES

Federal Aviation Administration (FAA) Radiation Alert



ALERT: Solar Radiation Alert at Flight Altitudes
Conditions Began: 2003 Oct 28 2113 UTC

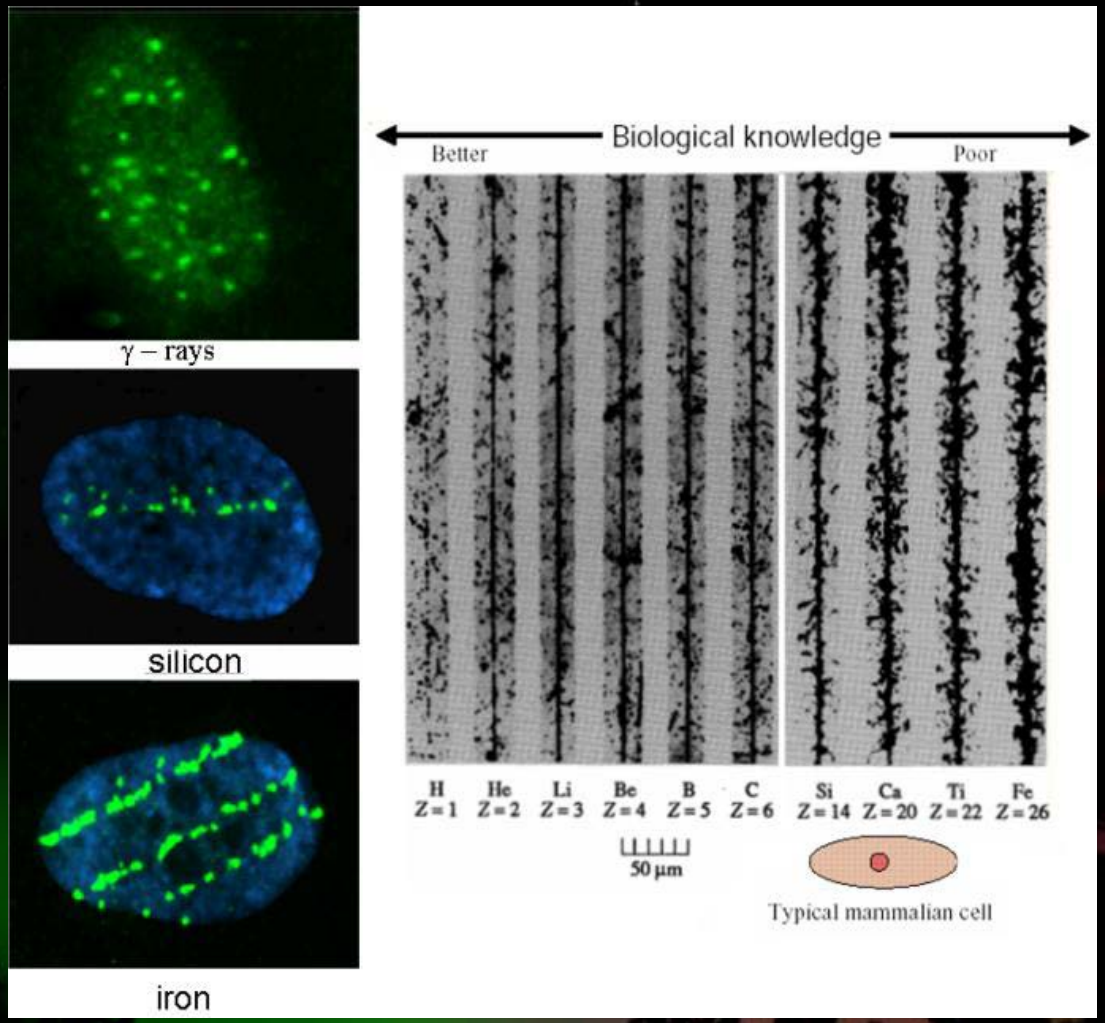
Comment:

Satellite measurements indicate unusually high levels of ionizing radiation, coming from the sun. This may lead to excessive radiation doses to air travelers at Corrected Geomagnetic (CGM) Latitudes above 35 degrees north, or south.

Avoiding excessive radiation exposure during pregnancy is particularly important.

Reducing flight altitude may significantly reduce flight doses. Available data indicates that lowering flight altitude from 40,000 feet to 36,000 feet should result in about a 30 percent reduction in dose rate. A lowering of latitude may also reduce flight doses but the degree is uncertain. Any change in flight plan should be preceded by appropriate clearance.

Ionizing Radiation



"In space, each cell within an astronaut is exposed every few days to a nuclear particle that comprises the GCR."

From NASA/TP-2013-217375, Cucinotta, et al. http://ston.jsc.nasa.gov/collections/TRS/_techrep/TP-2013-217375.pdf

Ionizing Radiation Effects

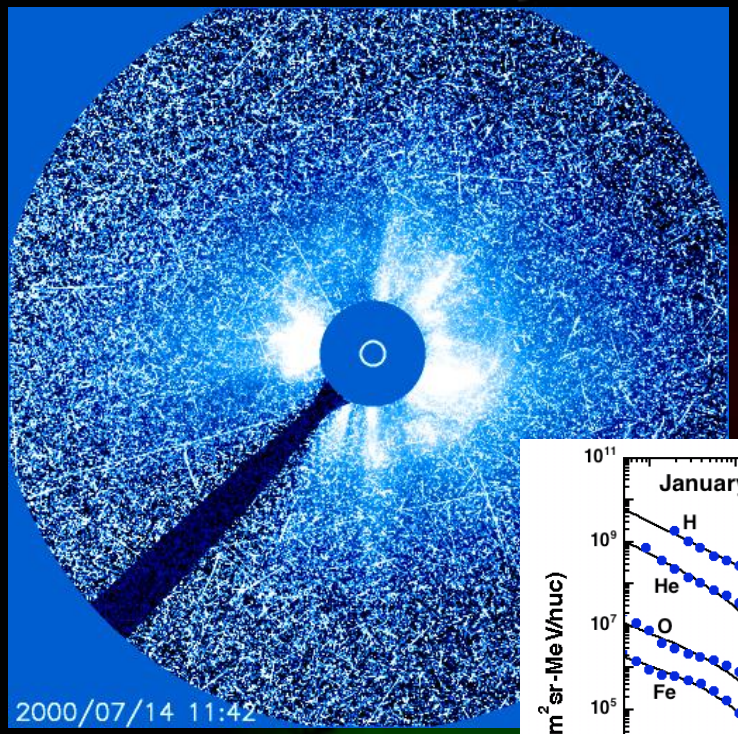
Long term

- Probability of occurrence in a population is function of dose. These are random, or non-threshold effects.
- Cancer
- Leukemia
- Genetic Effects

Short term

- Tissue Reactions - severity is directly related to dose
- Radiation Induced Cataract
- Sterility
- Radiation ‘Sickness’, Nausea
- Skin Reddening

Source Terms – Solar Particle Events



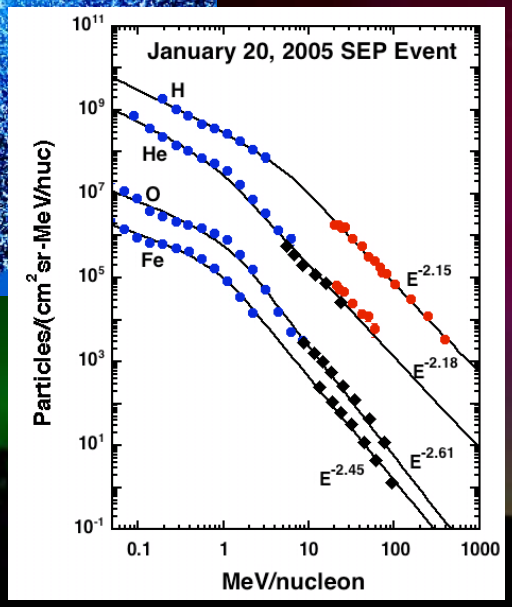


Image Credit – R.A. Mewaldt

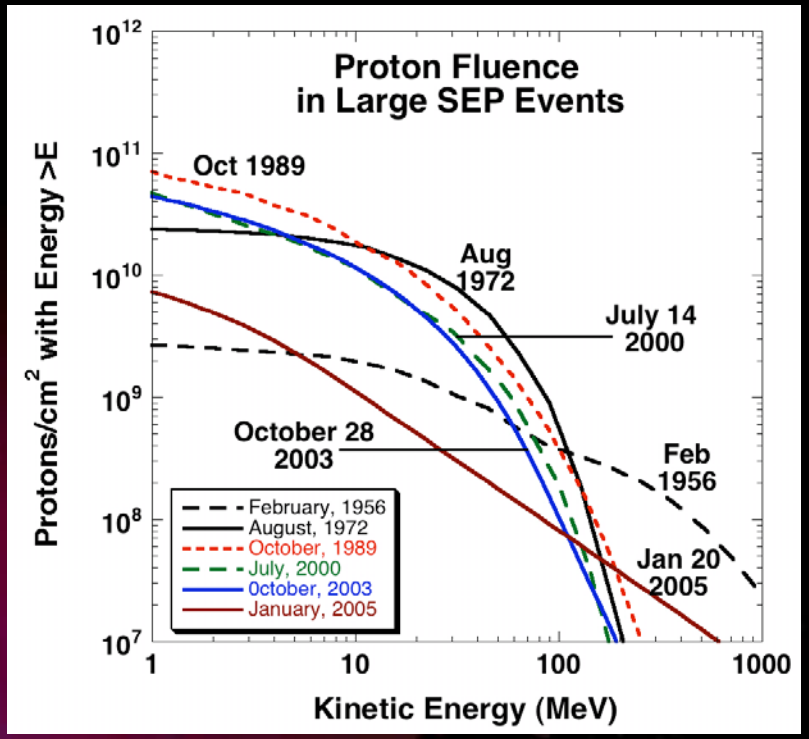
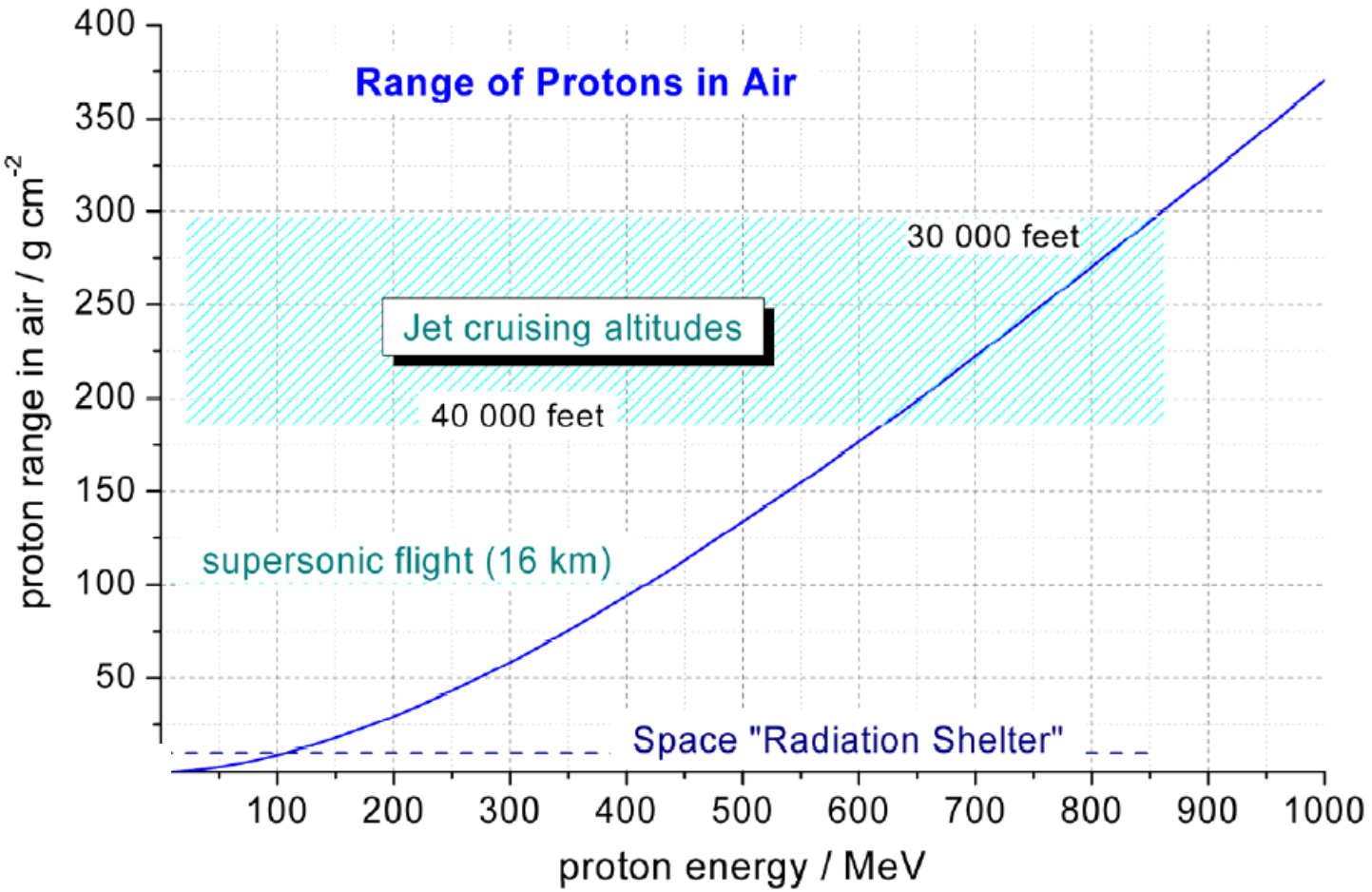


Image Credit – R.A. Mewaldt

Atmospheric Shielding: Range of Protons in the Atmosphere



Matthias M. Meier & Daniel Matthiae, 2013

Ionizing Radiation
Dose Ranges
(Sievert)

acute exposure = all at once; chronic = hours, days, years

Whole body, acute: G-I destruction; lung damage; cognitive dysfunction (death certain in 5 to 12 days)*

Cancer Radiotherapy
total doses to tumor

Whole body, acute: cerebral/ vascular breakdown (death in 0-5 days)*

Life Span Study (A-bomb survivor epidemiology)

Total Body Irradiation (TBI) Therapy

Whole body, acute: circulating blood cell death; moderate G-I damage (death probable 2-3 wks)*

Acute Radiation Syndromes

Whole body, acute: marked G-I and bone marrow damage (death probable in 1-2 wks)*

Charged particle event (Solar flare) dose on moon, no shielding

Estimated dose for 3-yr Mars mission (current shielding)

Early, transient skin erythema (2-24 hr onset)

Temporary epilation (3 wk onset)

Main erythema reaction (10 day onset)

Permanent epilation (3 wk onset)

Human LD_{50} range acute exposure **no** medical intervention*

Human LD_{50} range acute exposure with medical intervention

*__Note:__ Whole body acute prognoses assume **no** medical intervention (G-I = gastrointestinal)

Office of Science
U.S. DEPARTMENT OF ENERGY

Cancer Epidemiology

Evidence for small increases in human cancer above 100 mSv acute exposure or 200 mSv chronic exposure

Typical mission doses on International Space Station (ISS)

Ramsar, Iran high natural bkg/yr

DHS emergency guideline to save a life: 250 mSv

Interplanetary Space natural bkg/yr

DOE Low Dose Program

Kerala coast, India high natural bkg/yr

DHS emergency guideline for public relocation: 20 mSv/yr (2 rem/yr)

Guarapari, Brazil high natural bkg/yr

DOE, NRC dose limit for workers: 50 mSv/yr (5 rem/yr)

Typical added annual dose for commercial airline flight crews

Medical Diagnostics (A-O)

see chart >>

Airport x-ray whole body scanner: 0.00007 mSv/scan

(Limit = 0.25 mSv/yr ≈ 4000 scans/yr)

DOE facility releases

Natural background, USA average ≈ 3.1 mSv/yr (includes radon)

Yangjiang, China high natural bkg/yr

Regulations & Guidelines

Round-trip Los Angeles – New York (≈ 0.037 mSv)

EPA dose limit public drinking water systems: 0.04 mSv/yr

EPA dose limit from release in air: 0.1 mSv/yr

NRC cleanup criteria for site decommissioning / unrestricted use: 0.25 mSv/yr

DOE, NRC dose limit for the public: 1 mSv/yr (100 mrem/yr) (ICRP, NCRP)

Medical Diagnostics mGy
(Estimated maximum organ dose)

X-ray films	
A – Chest (PA & Lat)	0.14
B – Dental Panoramic	0.7
C – Lumbar-Sacral Spine	2 – 3
D – Mammogram	2 – 4
Radiotracer Imaging	
E – Heart Stress (Tc-99m)	6 – 12
F – Bone (Tc-99m)	4 – 15
G – Dual Isotope Stress Test	40 – 45
H – PET: F-18 FDG (bladder)	55 – 80
CT Scans (X-ray) (multiple scan average dose)	
I – Chest CT	20 – 30
J – Head CT	30 – 50
K – Abdominal CT	22 – 60
L – Full Body CT	50 – 100
Fluoroscopy/Procedures	
M – Barium Contrast G.I.	10 – 22
N – Cardiac Catheterization	12 – 40
O – TIPS Procedure	400 – 1400

(TIPS: Transjugular Intrahepatic Porto-systemic Shunt

LD_{50} = Lethal Dose to 50% (whole body dose that results in lethality to 50% of exposed individuals in 30-60 days)

Dose Equivalent: 1 Sievert = 100 rem = (absorbed dose x radiation quality)
Absorbed Dose: 1 Gray = 100 rad
1 Sv ≈ 1 Gy for x- and gamma-rays
(" ≈ " stands for "approximately equal to")

NOTE: This chart was constructed with the intention of providing a simple, user-friendly, "order-of-magnitude" reference for radiation exposures of interest to scientists, managers, and the general public. In that spirit, most quantities are expressed as "dose equivalent" in the more commonly used radiation protection units, the rem and Sievert. Medical diagnostics are expressed as estimated maximum organ dose; as they are not in "effective dose" they do not imply an estimation of risk (no tissue weighting). Dose limits are in effective dose, but for most radiation types and energies the difference is numerically not significant within this context. It is acknowledged that the decision to use these units is a simplification, and does not address everyone's needs. (NRC = Nuclear Regulatory Commission; EPA = Environmental Protection Agency; DHS = Department of Homeland Security)
Disclaimer: Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information disclosed.

Chart compiled by NF Metting, Office of Science, DOE/BER. "Orders of Magnitude" revised June 2010
http://www.lowdose.energy.gov/

Source: Office of Biological and Environmental Research (BER), Office of Science, U.S. Department of Energy
http://www.science.doe.gov/ober/