Radiation Environment and Radiation Dosimetry in the Upper Atmosphere

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Outline

- Radiation terminology
- Radiation environment in upper atmosphere
- Measurements of the upper atmospheric radiation environment
- Examples of dosimetry results

Absorbed Dose

(ICRU) report 51 titled Quantities and Units in Radiation Protection Dosimetry, the fundamental dosimetric quantity is the absorbed dose, D. According to International Commission on Radiation Units and Measurements

Absorbed dose, D, is the quotient of by, where is the mean energy imparted by ionizing radiation to matter of mass (ICRU, 1993).

$$D = \frac{d\bar{\varepsilon}}{dm}$$

Unit: J kg^{-1}

The name for the unit of absorbed dose is gray (Gy).

Dose Equivalent

The dose equivalent, H, is the product of Q and D at a point in tissue, where D is the absorbed dose and Q is the quality factor at that point (ICRU, 1993).

$$H = D * Q$$

Unit: J kg^{-1}

The name for the unit of dose equivalent is sievert (Sv).

Operational environments for space missions.

Earth Orbits (LEO, MEO & GEO)

Asteroids

Earth-Moon Transit

Lunar Surface

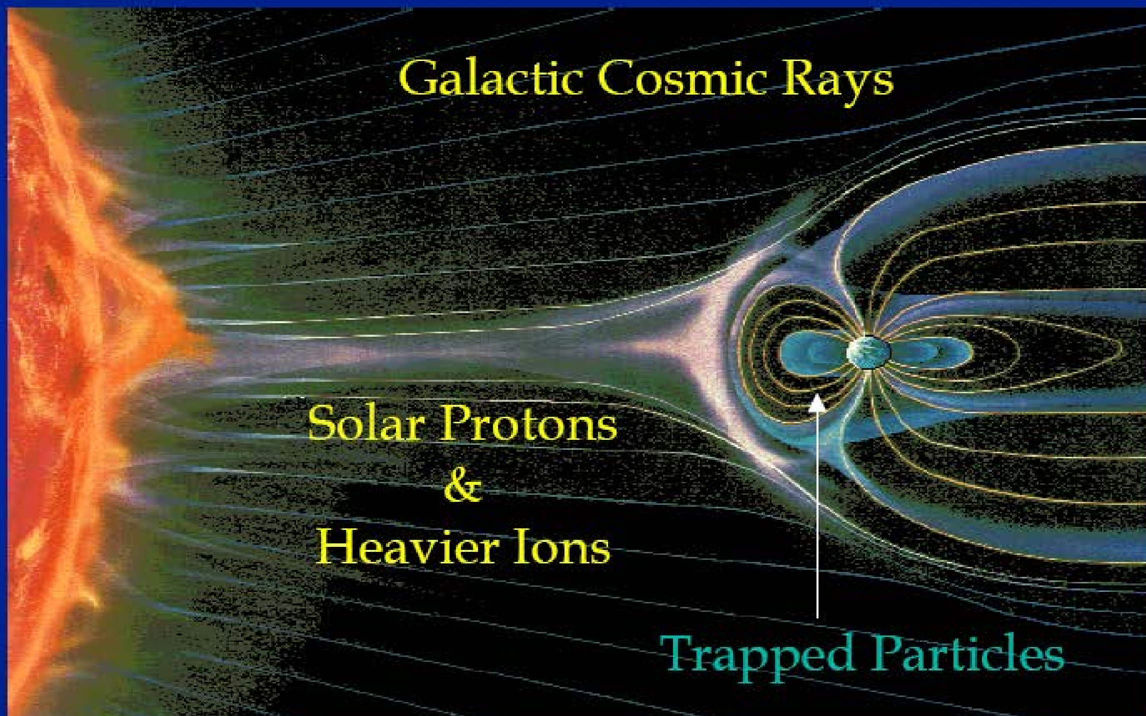
Interplanetary Space

http://universe-review.ca/I07-02-SolarSystem.jpg

Martian Surface

www.nasaimages.org

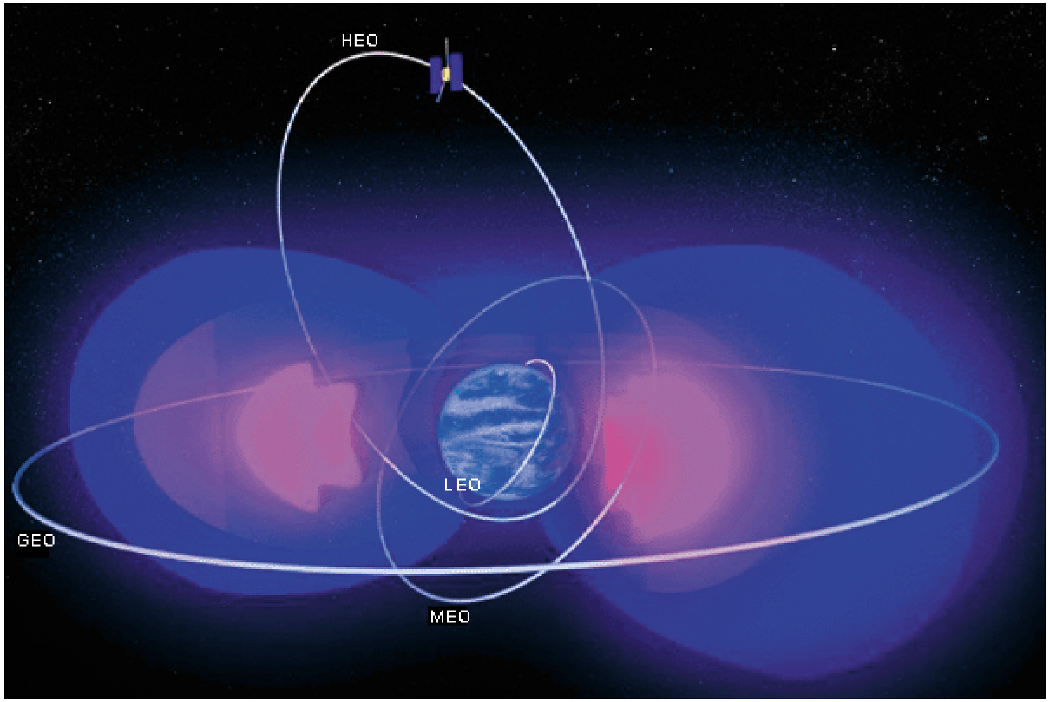
The Radiation Environment



Nikkei Science, Inc. of Japan, by K. Endo

J. Barth/Code 562

Trapped Radiation: The Van Allen Radiation Belts



The Van Allen radiation belts and typical satellite orbits. Key: GEO—geosynchronous orbit; HEO—highly elliptical orbit; MEO—medium Earth orbit; LEO—low Earth orbit. (Illustration by B. Jones, P. Fuqua, J. Barrie, The Aerospace Corporation.)
http://www.aero.org/publications/crosslink/summer2003/02.html

- LEO orbits are lower than the most intense regions of the belts.
- MEO and HEO orbits will encounter the belts. Some orbits are chosen to avoid the most intense regions.
- GEO lies beyond the belts for the most part.

Radiation Environment in Upper Atmosphere

- Galactic cosmic and solar particle radiation interact in the upper atmosphere of the Earth
- The intensity of the primary and secondary components of this radiation field increase with altitude and latitude
- The FAA has estimated that aircrew exposures range from 0.2 to 9.1 mSv/yr (as compared to 0.5 mSv/yr exposure of the average nuclear power plant worker)

Radiation Environment in Upper Atmosphere

Galactic Cosmic Radiation (GCR)

- **Diffuse energetic atomic nuclei from supernovae**
- **Omni-directional**
- **Protons (87%), Helium Ions (12%), Heavier Ions (1%)**
- **Dominant exposure to aircrew**

Atmospheric Exposure Variables

- **Altitude: Shielding by air molecules**
  - **1030 g/cm2 at sea level**
  - **55 g/cm2 at 20 km (66,000 ft)**

Dose Equivalent rate H at 20 km approx 400 x H at sea level

- **Latitude: Shielding by geomagnetic field**
  - **Bends lower energy particles back into space**

H at poles approx 6 x H at equator (at 20 km altitude)

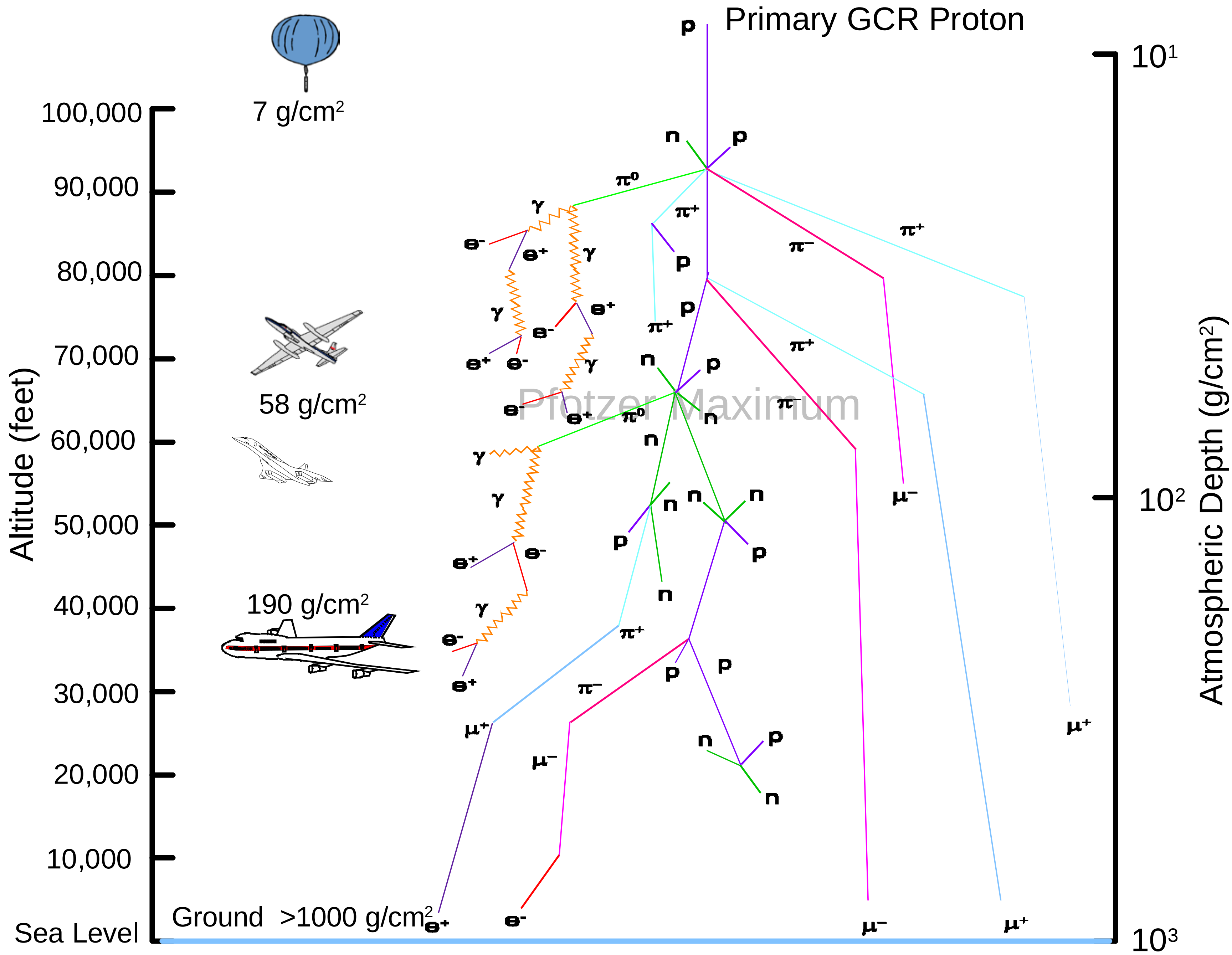
  - **Effect on *H* increases with altitude**

Atmospheric Exposure Variables (Cont'd)

- Time in Solar Cycle (Heliocentric Potential)
  - Magnetic field of the "solar wind"
  - 11-year sunspot cycle:
    - Radiation MAXIMUM at sunspot MINIMUM (2016–2020)
  - Effect on *H* increases with geomagnetic latitude and altitude

Pfotzer Maximum

- **As GCR enters atmosphere it collides with air molecules, breaking apart nuclei, producing secondary elements of ionizing radiation**
- **On descent through the atmosphere, radiation *increases* due to secondary particles**
  - **Intensity is *lower* at 80,000 feet than it is at 60,000 feet, where intensity is highest**
  - **Further descent: Progressively decreasing level of radiation**
- **Area of maximum radiation intensity known as *Pfotzer Maximum* (approx 65,000 feet)**



Primary GCR Proton
7 g/cm²
58 g/cm²
190 g/cm²
Pfotzer Maximum
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
Sea Level
Ground >1000 g/cm²
Altitude (feet)
10¹
10²
10³
Atmospheric Depth (g/cm²)

Terrestrial Environments: Atmospheric Neutrons

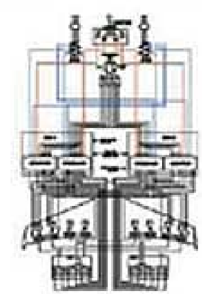
Possible Effects to:

Aircraft Crew

Avionics

Modern aircraft are controlled with “fly-by-wire systems that may be susceptible to effects from atmospheric neutrons.

http://www.aerospace-technology.com/projects/a330/images/A330_cockpit1.jpg



http://www.moog.com/img/2/challenger.jpg

Typical Annual Occupational Doses

Source	Dose (mSv)
Artificial sources	
Nuclear industry	
Uranium mining	4.5
Uranium milling	3.3
Enrichment	0.1
Fuel fabrication	1.0
Nuclear reactors	1.4
Reprocessing	1.5
Medical uses	
Radiology	0.5
Dentistry	0.06
Nuclear medicine	0.8
Radiotherapy	0.6
Industrial sources	
Irradiation	0.1
Radiography	1.6
Isotope production	1.9
Well-logging	0.4
Accelerators	0.8
Luminizing	0.4
Natural sources	
Radon sources	
Coal mines	0.7
Metal mines	2.7
Premises above ground (radon)	4.8
Cosmic sources	
Civil aircrew	3.0

Data for 1990–1994 Source: UNSCEAR Report 2000, Vol. 1, Annex E, Tables 12, 16, 22 and 43

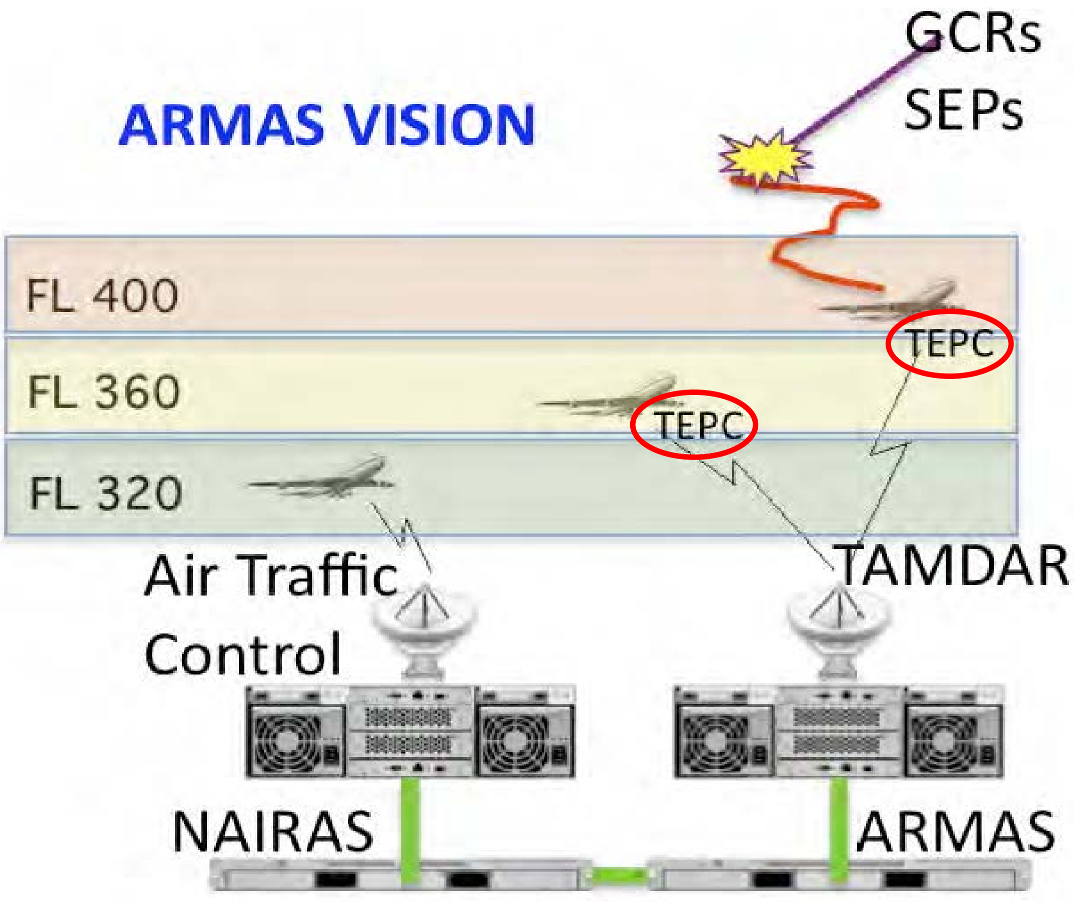
Doses on flights:

Cities	Effective Dose (μSv)
Vancouver ➤ Honolulu	14.2
Frankfurt ➤ Dakar	16.0
Madrid ➤ Johannesburg	17.7
Madrid ➤ Santiago de Chile	27.5
Copenhagen ➤ Bangkok	30.2
Montreal ➤ London	47.8
Helsinki ➤ New York (JFK)	49.7
Frankfurt ➤ Fairbanks, Alaska	50.8
London ➤ Tokyo	67.0
Paris ➤ San Francisco	84.9

Source: Exposure of Aircraft Crew to Cosmic Radiation, a report of the EURADOS Working Group 5 to the Group of Experts established under Article 31 of the Euratom Treaty. European Commission

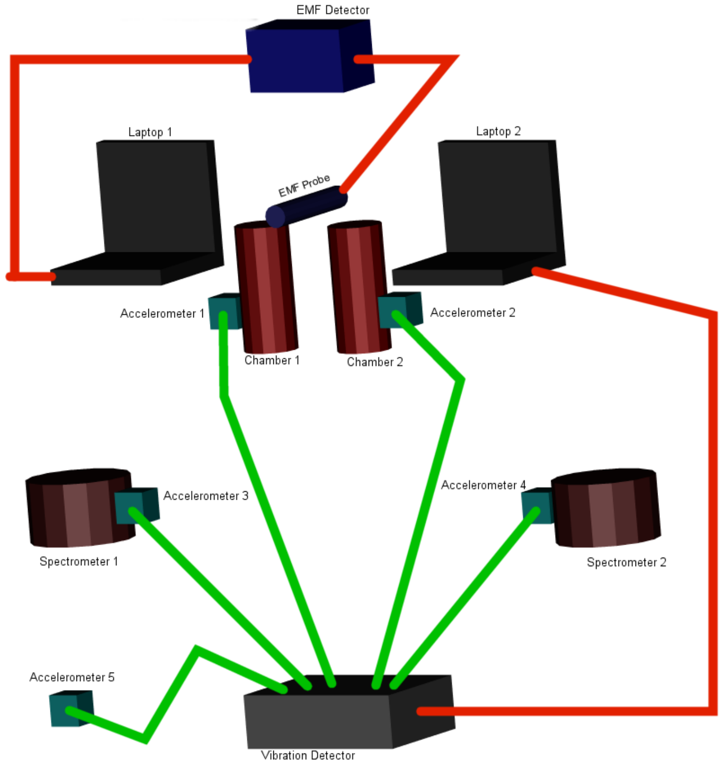
http://www.iaea.org/Publications/Booklets/RadPeopleEnv/pdf/chapter_9.pdf

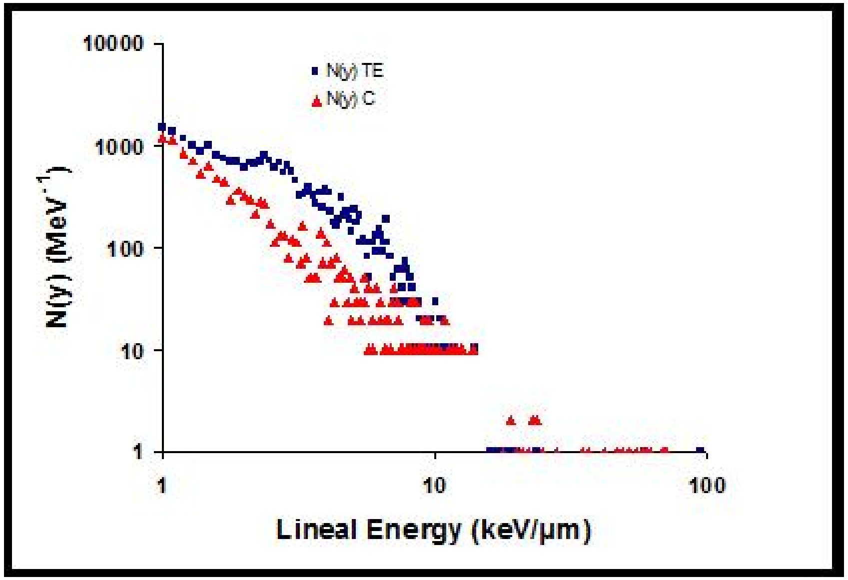
Current Research: Automated Radiation Measurements for Radiation Safety (ARMAS)



PVAMU is responsible for the operation of the tissue equivalent proportional counters (TEPC). The TEPC is an "active" dosimeter that measures adsorbed dose to a simulated small volume of human tissue.

ARMAS work includes ground based experiments designed to reference small, silicon based radiation dosimeters with the TEPC.


EMF Detector
Laptop 1
Laptop 2
EMF Probe
Accelerometer 1
Accelerometer 2
Chamber 1
Chamber 2
Accelerometer 3
Accelerometer 4
Spectrometer 1
Spectrometer 2
Accelerometer 5
Vibration Detector


10000
1000
100
10
1
N(y) TE
N(y) C
N(y) (MeV⁻¹)
1
10
100
Lineal Energy (keV/µm)

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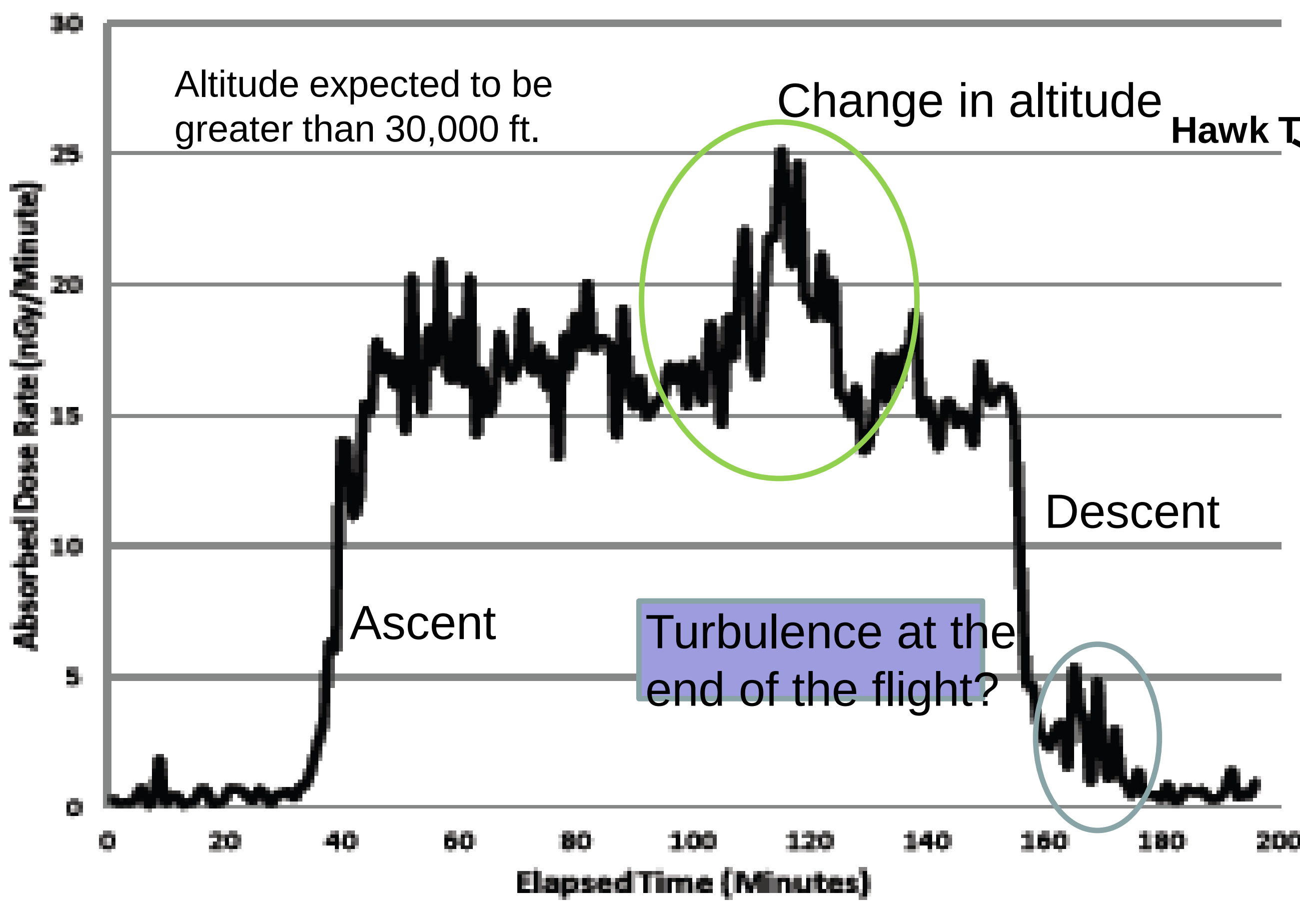
Center for Radiation Engineering and Science for Space Exploration

Current Research: Preliminary Hawk TEPC data from commercial FeDEx flights.
Example: Houston to Los Angeles, 8/25/11, 12 am – 3am.
Dose equivalent rate: about 1.8 uSv/hr, total equivalent dose: about 4 uSv

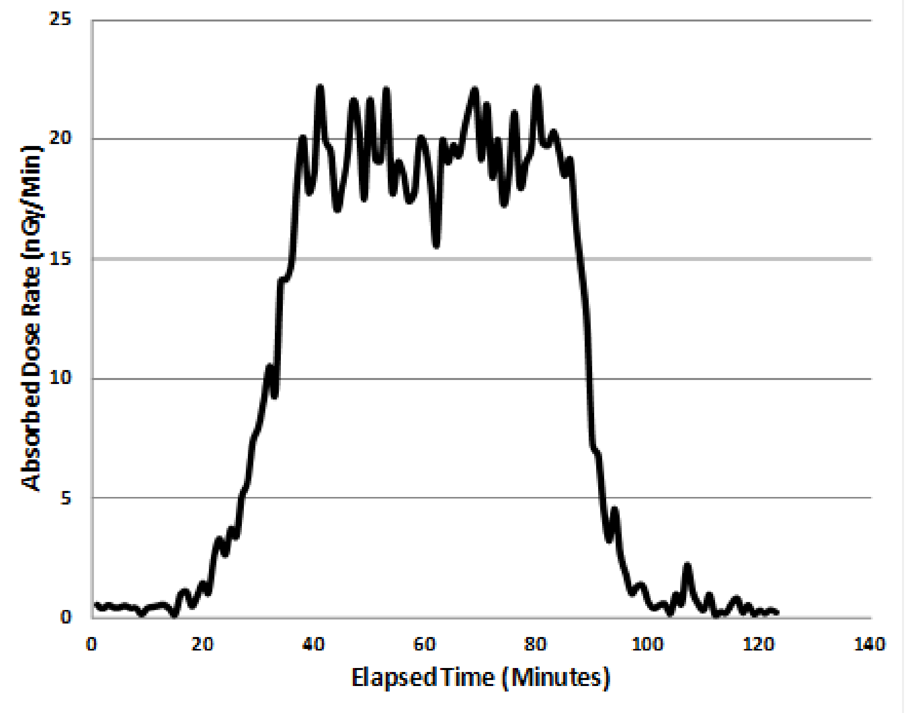


Hawk has GPS capabilities, but package buried in flight. No GPS data during flights, but GPS clear on the ground.

National Aeronautics and Space Administration

Future work to include studies on electronic effects.

Dosimetry Results: Commercial Aircraft

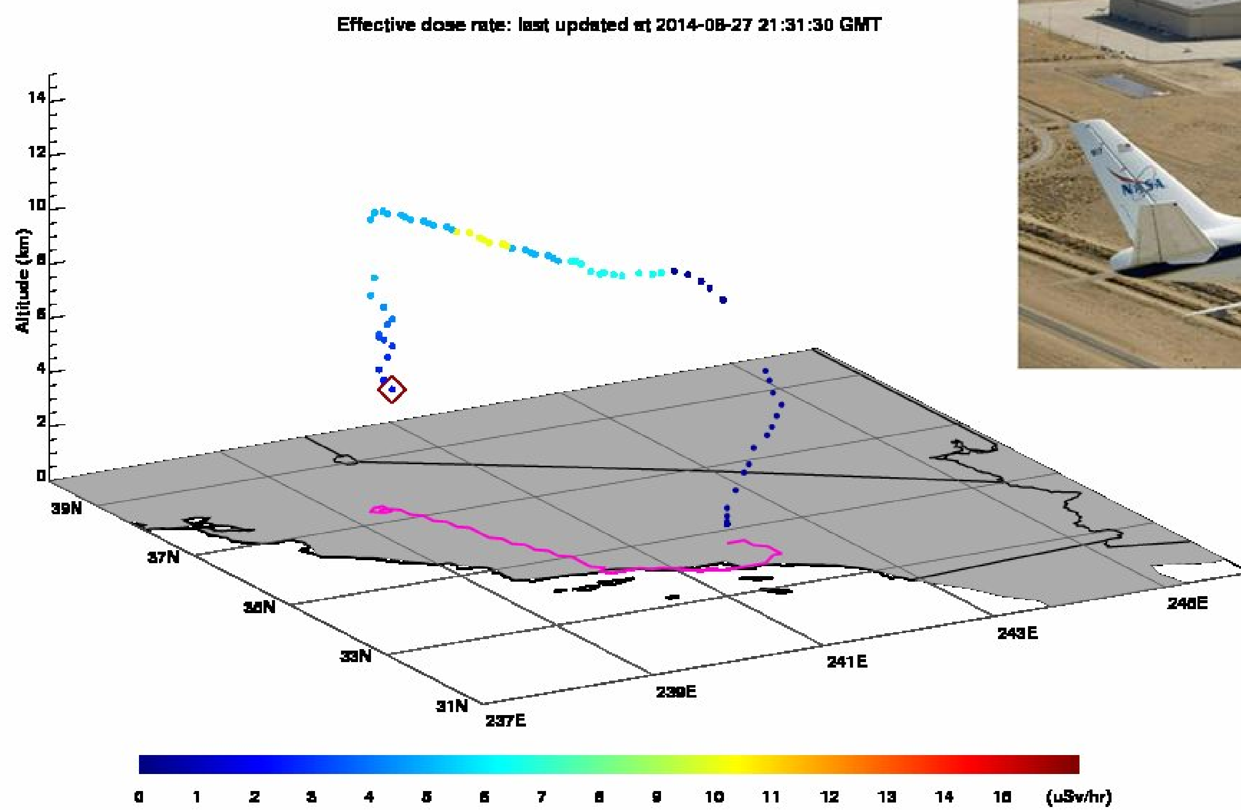


Measured absorbed dose rate (nGy/min) as a function of elapsed time in minutes for flight from Holbrook, NY to Indianapolis, IN.

Dosimetry Results: Commercial Aircraft

Flight Origin			Flight Destination			Flight Total Absorbed Dose	Absorbed Dose Rate At Cruise Altitude	Total Dose Equivalent	Dose Equivalent Rate At Cruise Altitude	Average Quality Factor
Date	Time (PST)	Location	Date	Time (PST)	Location	(µGy)	(µGy/Hour)	(µSv)	(µSv/Hour)	At Cruise Altitude
04/28/11	5:26 AM	Holbrook, NY	04/28/11	7:43 AM	Memphis, TN	2.34	1.28	5.88	3.29	2.55
06/15/11	6:56 PM	Holbrook, NY	06/15/11	8:40 PM	Indianapolis, IN	1.19	1.17	2.63	2.70	2.24
08/25/11	12:06 AM	Houston, TX	08/25/11	3:07 AM	Los Angeles, CA	2.20	1.03	3.96	1.81	1.72

Preliminary ARMAS-LITE dose rate measurements from a silicon based radiation dosimeter. The Teledyne “Micro Dosimeter” is compact and can be installed on various flight platforms.



These measurements were taken on-board a NASA-Armstrong (CA) DC-8 research aircraft.

Dr. W. Kent Tobiska
Space Environment Technologies.

Photo: http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-050-DFRC.html

PVAMU mechanical engineering graduate student Stephen Bacon working at NASA-Armstrong. Mr. Bacon is working on integration equipment for payload integration of various radiation instruments (including the new ARMAS-LITE radiation dosimetry system.

Kent Tobiska discusses the new ARMAS-LITE instrument with Stephen Bacon, 8/19/14.

Stephen Bacon and NASA-Armstrong Aerospace meteorologist Scott Wiley, 8/20/14.