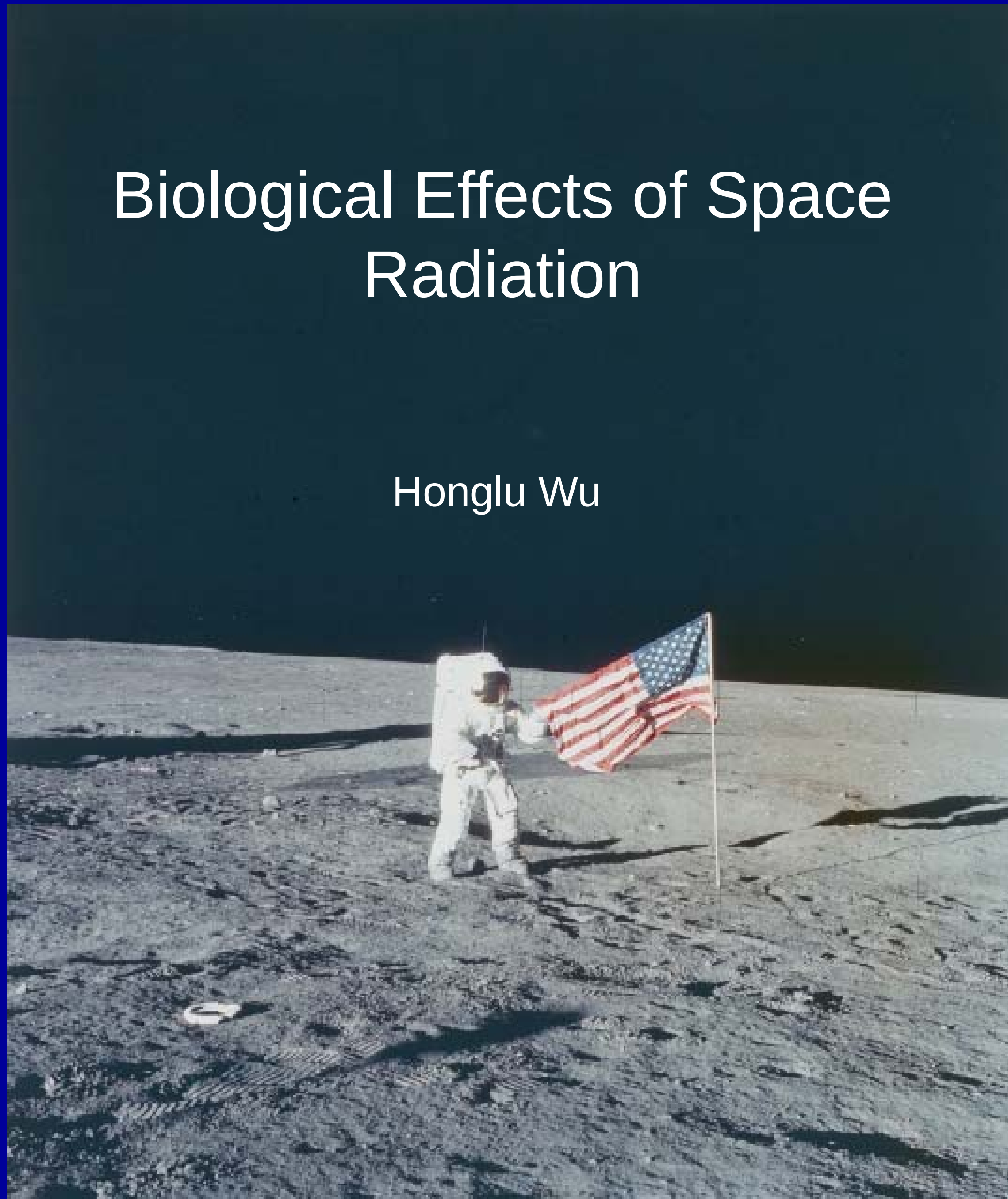
Biological Effects of Space Radiation

Honglu Wu

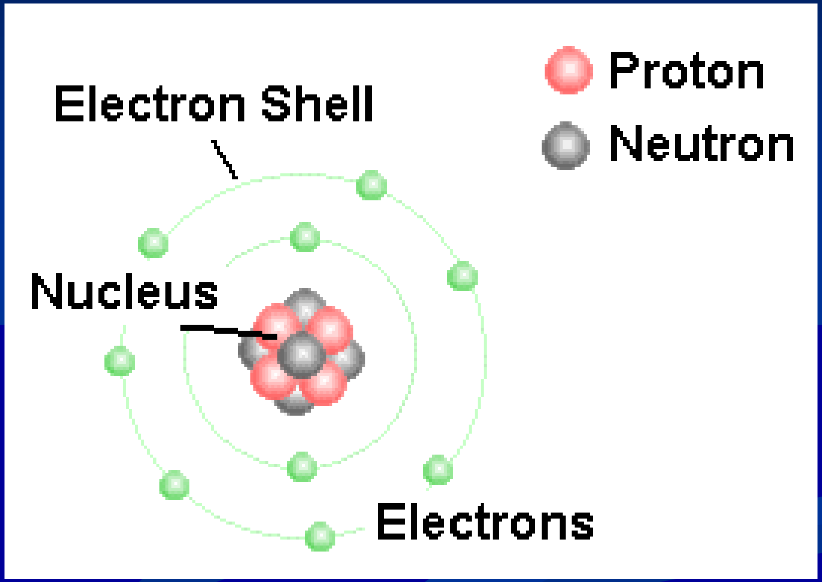


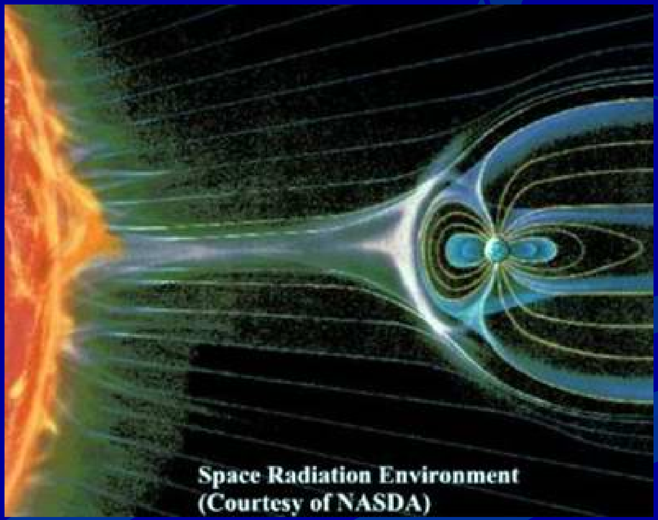
Outline of the presentation

- Brief introduction to the space radiation environment
- Space radiation health risks
- Challenges in radiation countermeasures
- Biodosimetry analysis

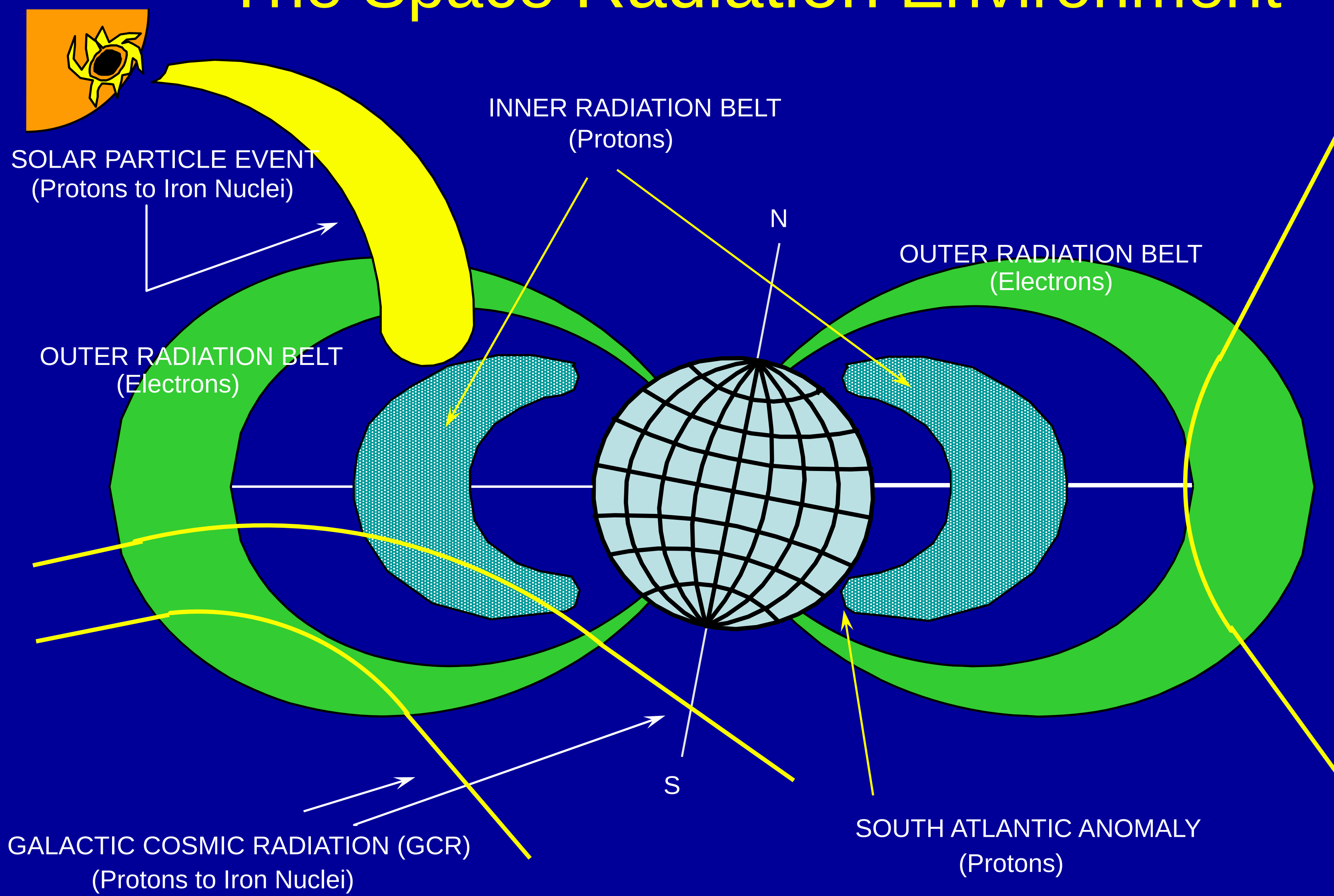
Space Radiation

- Space radiation consists of energetic charged particles (atoms with all of the electrons striped)
- Astronauts are exposed to secondary neutrons as well



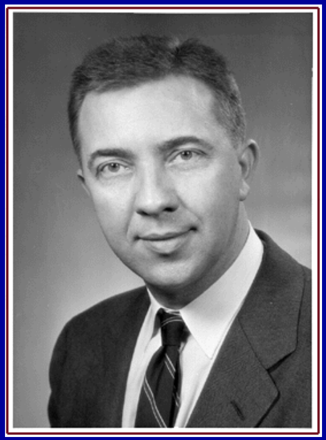


The Space Radiation Environment

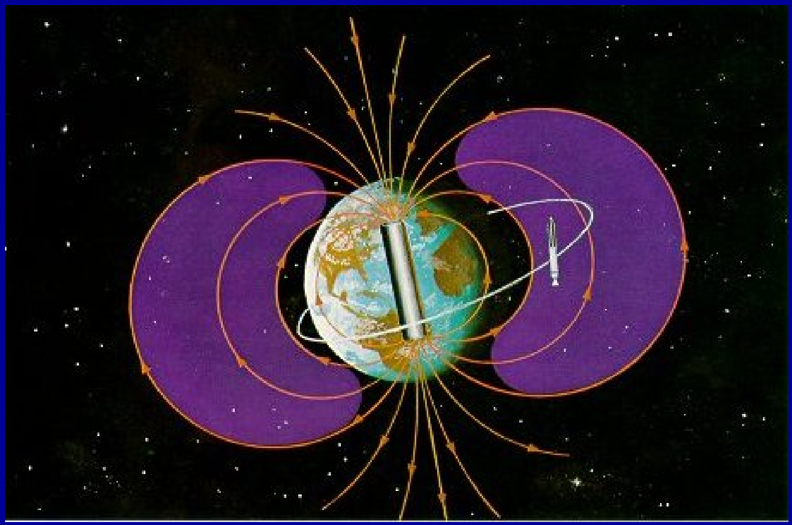


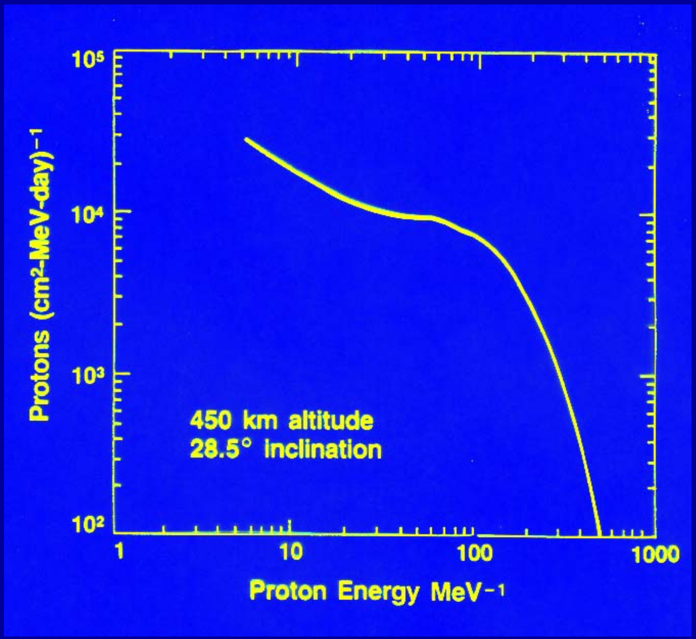
Representation of the major sources of ionizing radiation of importance to manned missions in low-Earth orbit. Note the spatial distribution of the trapped radiation belts.

Trapped Radiation (Van Allen Belt)



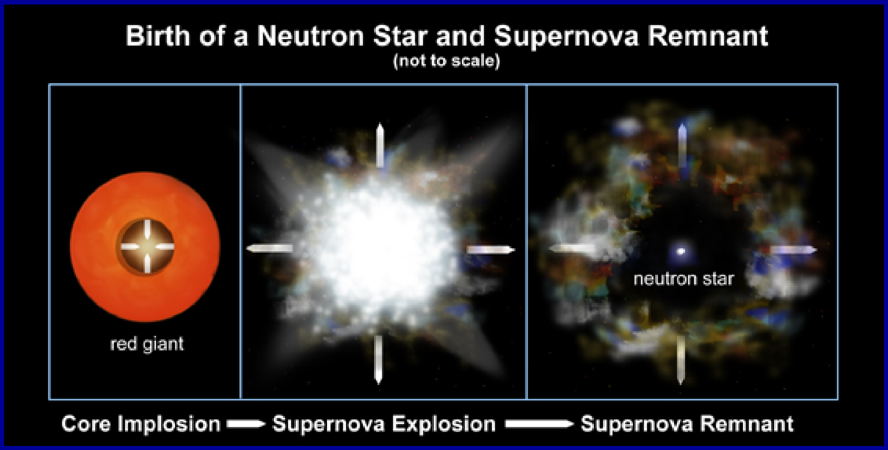
James Van Allen (1914 -)

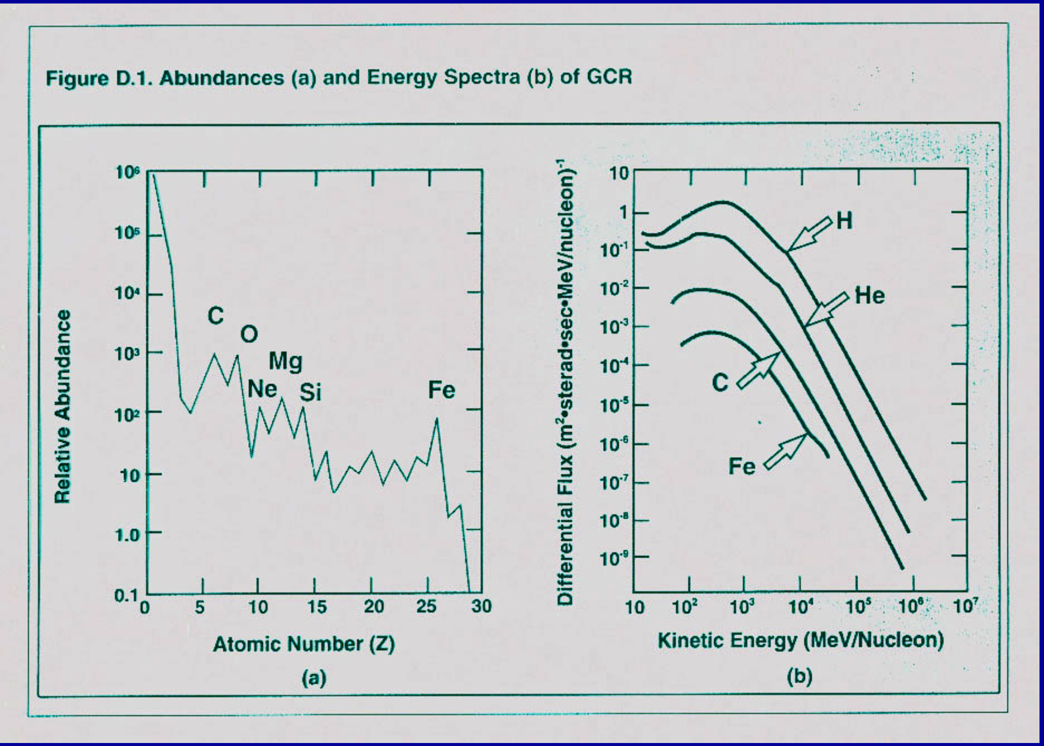




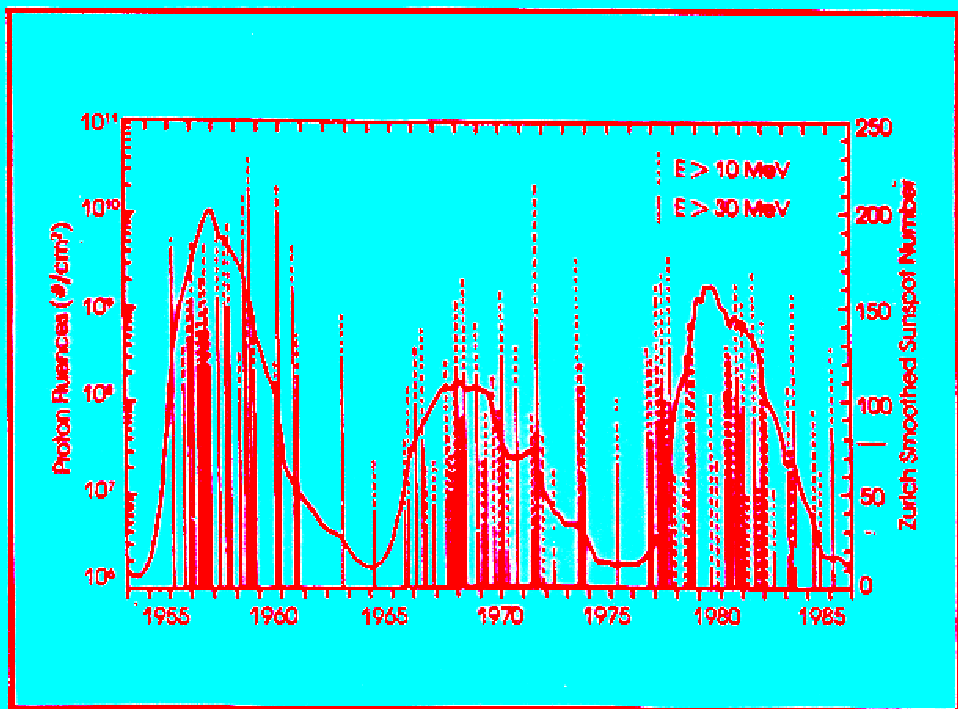
Energy spectrum of trapped protons

Galactic Cosmic Radiation (GCR)

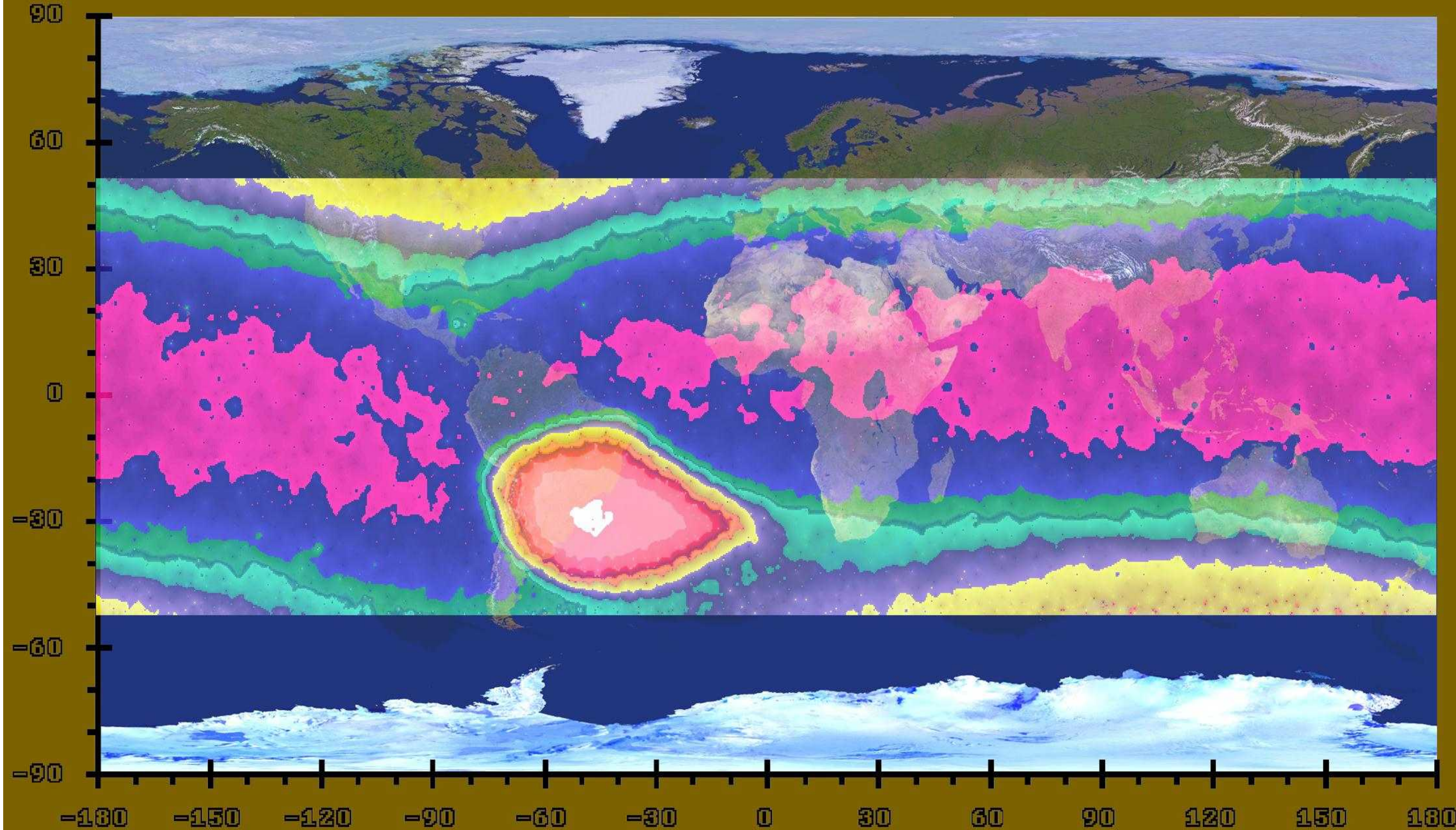




Solar Particle Event (SPE)



Sunspot Activity vs. Solar Flare Proton Flux
D.S. Nachtwey, NASA Johnson Space Center



Inclination = 51.6 deg.
Altitude ~ 385 km.
November 2, 1997 -
November 4, 1997

NASA-MIR 6 - Radiation Dosage
TEPC- PRIRODA

Secondary Neutrons

Summary of the Space Radiation Environment

- Major sources: Trapped protons, GCR, solar particle events

- Radiation type: Protons and heavy ions (high-LET), and secondary neutrons

- Dose rates vary from low (Trapped protons and GCR) to intermediate (SPE)

- Small amount of X-rays and gamma rays

- Ultraviolet radiation

Definitions

- Absorbed dose: The energy imparted per unit mass by ionizing radiation to matter at a specified point. The SI unit of absorbed dose is the joule per kilogram. The special name for this unit is the Gray (Gy).

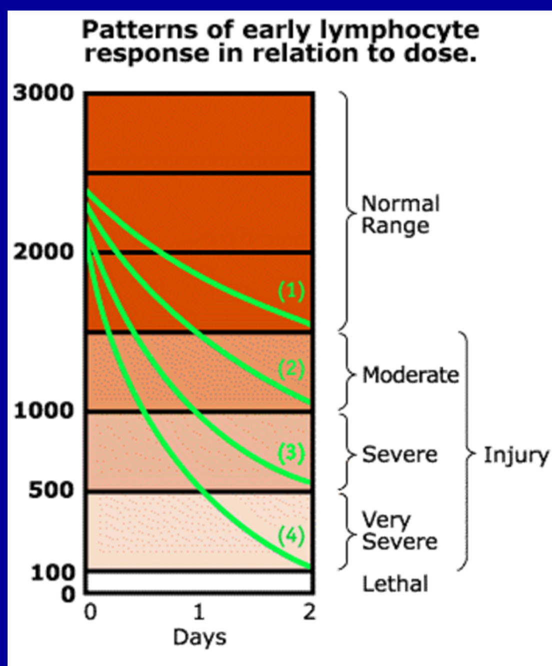
- Equivalent dose: A quantity used for radiation protection purposes that takes into account the different probability of effects that occur with the same absorbed dose delivered by radiations with different radiation weighting factors. Effective dose is measured in Sv.

- Linear energy transfer (LET): The amount of energy deposited by radiation per unit length of travel, expressed in keV per micron. High energy gamma, x-rays or light charged particles have low LET values, whereas heavy charged particles have high LET values.

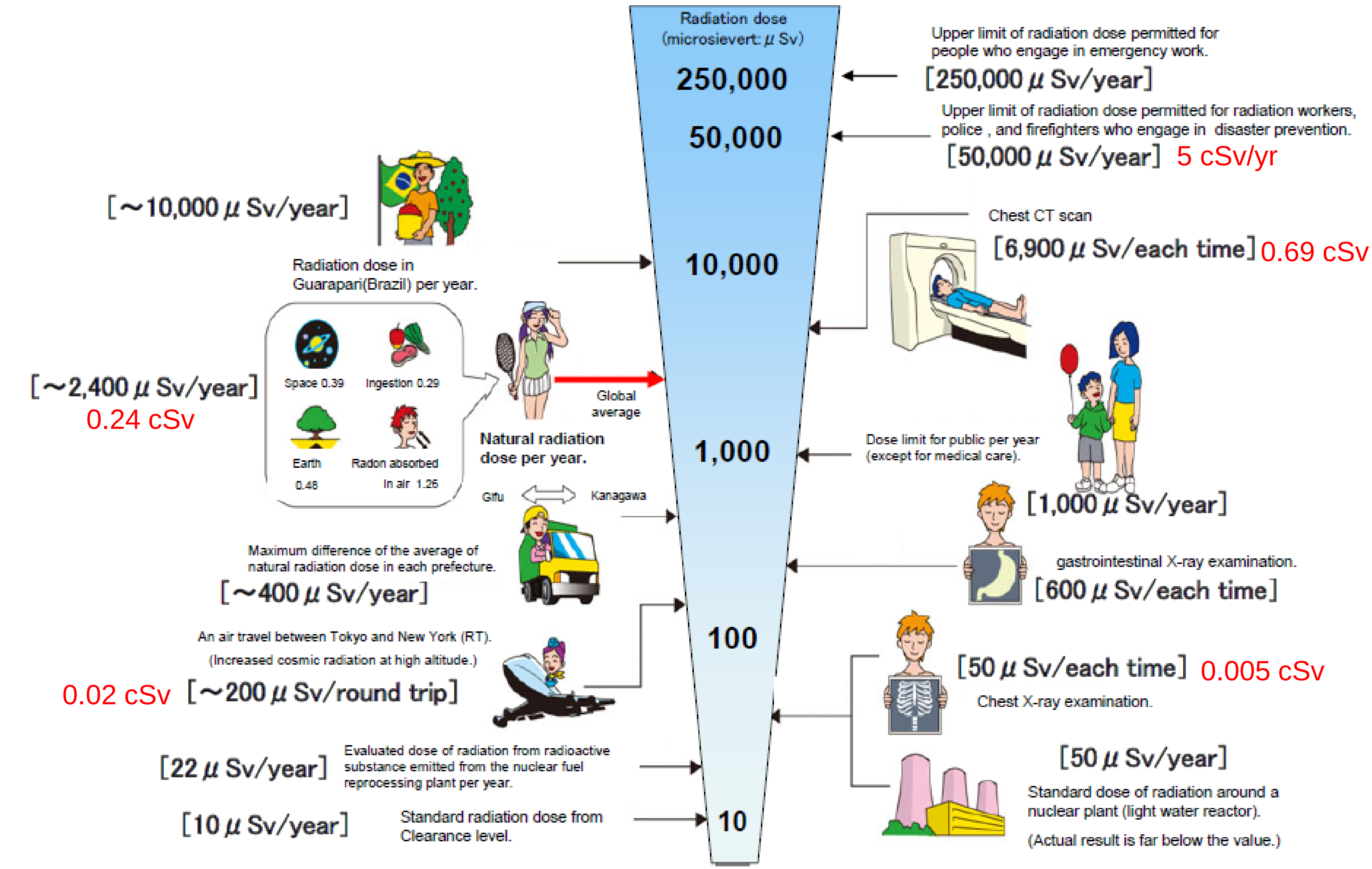
$$H = D\ Q(LET)$$

Acute radiation syndrome
(Acute whole body dose > 50 cSv)

- Vomiting
- Diarrhea
- Reduction in the number of blood cells
- Bleeding
- Hair loss
- Temporary sterility in males
- Lens opacity
- Others



Radiation in Daily Life



Living in Houston for one year 0.09 cSv/yr
Living in Denver for one year 0.3 cSv/yr

Doses Received from Spaceflight

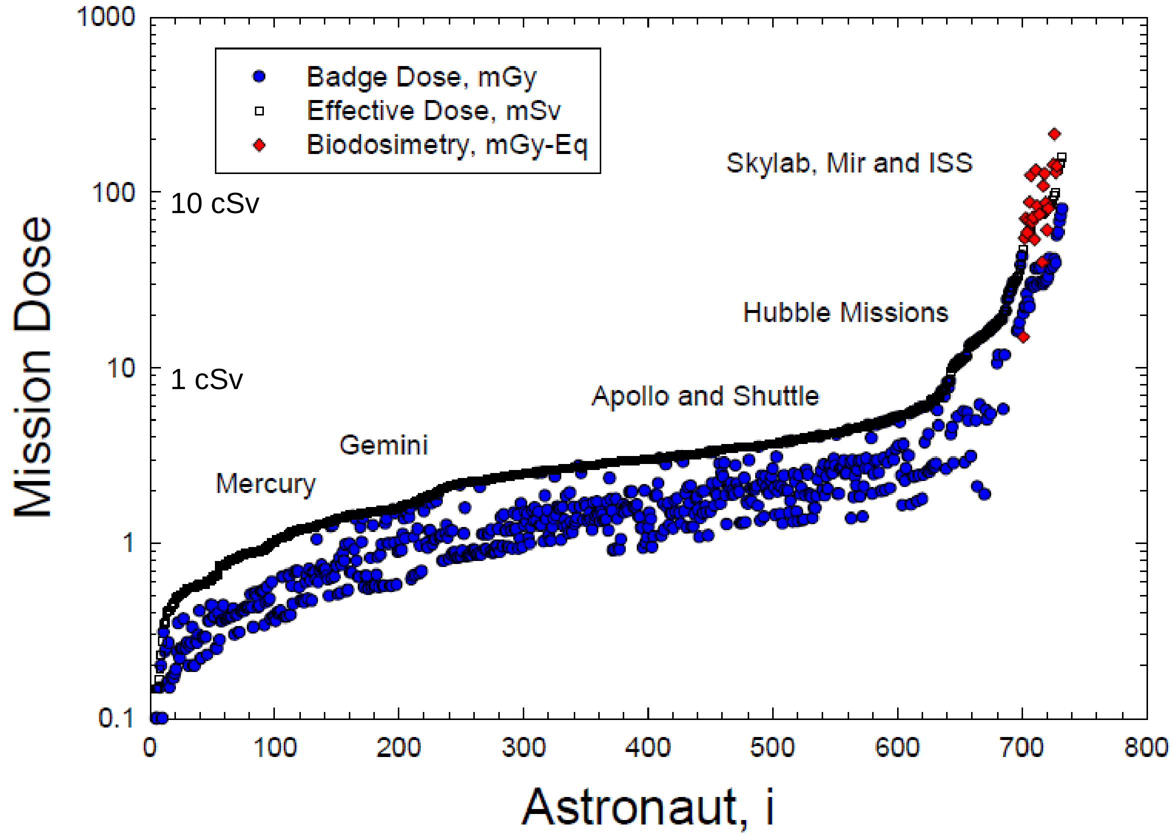


Figure 4-7. *Summary of mission personnel dosimetry from all past NASA crews (Cucinotta et al., 2008). Effective dose and population average biological dose-equivalent for astronauts on all NASA space missions, including Mercury, Gemini, Apollo, Skylab, Apollo-Soyuz, space shuttle, shuttle-Mir, and ISS missions.*

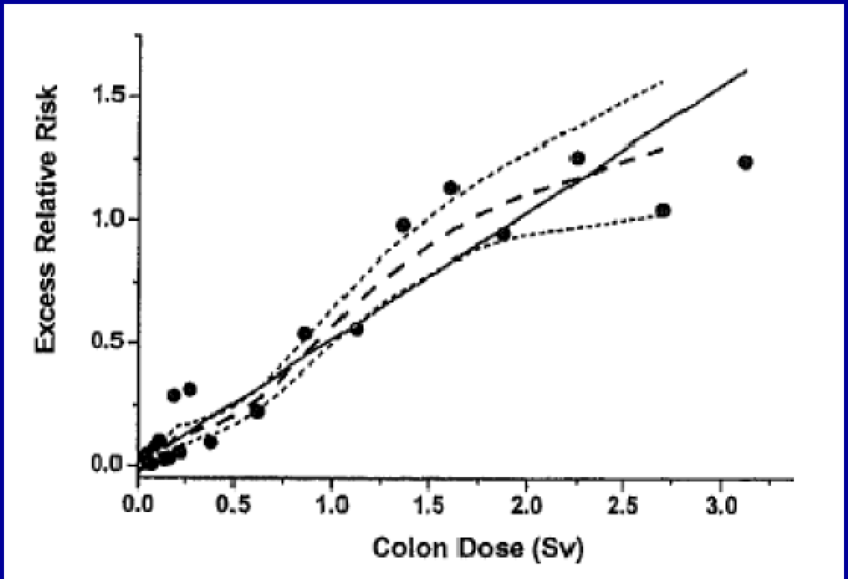
Cucinotta, HRP Evidence Book

Mission	Altitude (nm)	Inc. (deg)	Duration (days)	Dose (cSv)
STS-94	160	28.5	15.7	0.27
STS-95	310	28.5	8.9	2.1

Space Radiation Health Risks

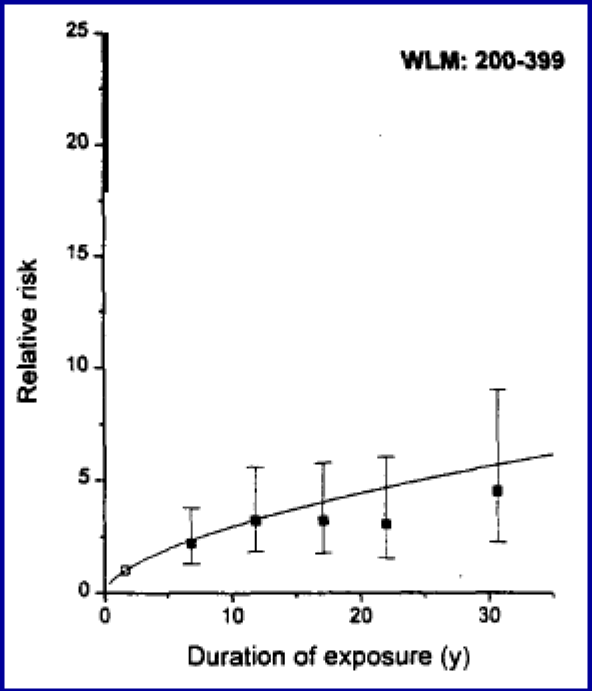
Carcinogenesis -- Increased cancer morbidity or mortality risk in astronauts may be caused by occupational radiation exposure

Low-LET -- Atomic bomb victims



Preston et al. 2003
Cucinotta, Evidence book

High-LET – Miners exposed to alpha particles



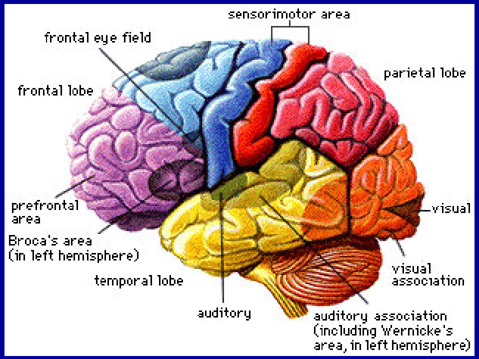
Lubin et al. 1995

Evidence from spaceflight??

	NASA January 1959-Feb 2012
Spacecraft Accidents	14
Non-Spacecraft Accidents	12
Cancer	9
Circulatory Disease	5
Other	4
Total	**44**

Cause of death of astronauts; Data from Mary Wear

- **Acute and late CNS risks --** Acute and late radiation damage to the central nervous system (CNS) may lead to changes in motor function and behavior, or neurological disorders.



Light flashes

Budinger, Lyman and Tobias 1972

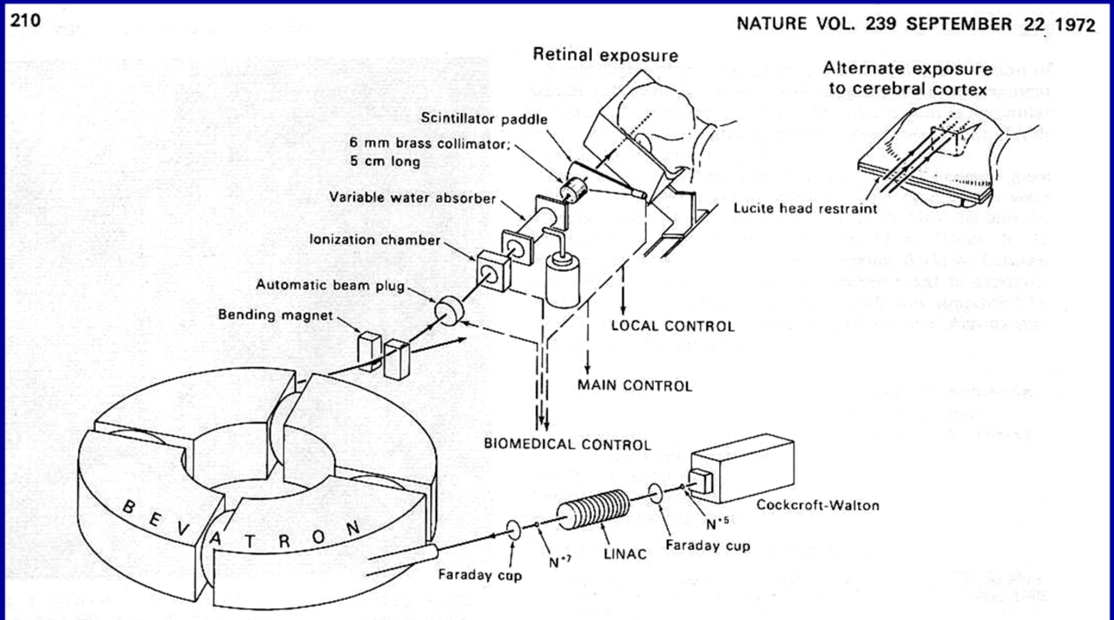


Fig. 1 Human eye and brain exposure—experimental configuration. Nitrogen ions, after final stripping, are injected into the Bevatron, accelerated to 266 MeV/nucleon, and stopped in known parts of the eye and brain.

- **Chronic and degenerative tissue risks --** Radiation exposure may result in degenerative tissue diseases (non-cancer or non-CNS) such as cardiac, circulatory, or digestive diseases, as well as cataracts.

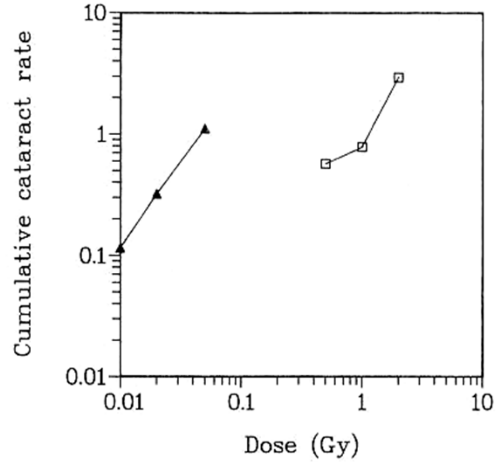
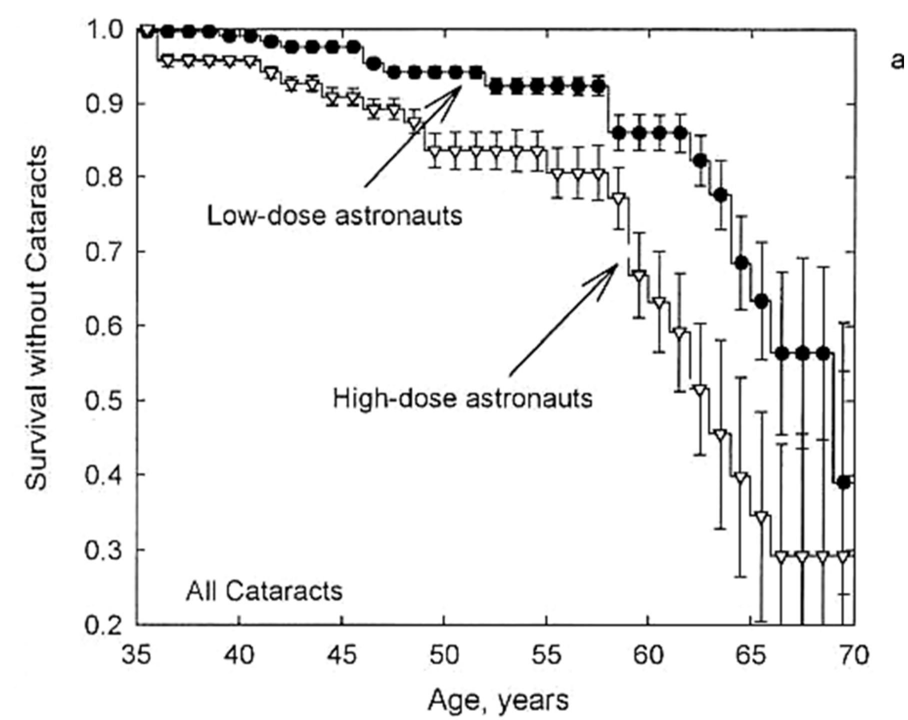


FIG. 2. Cumulative cataract rates (see text) for cataracts of grade 2 at 67 weeks postirradiation. □, X rays; ▲, iron ions. The lines joining the points are to guide the eye only.

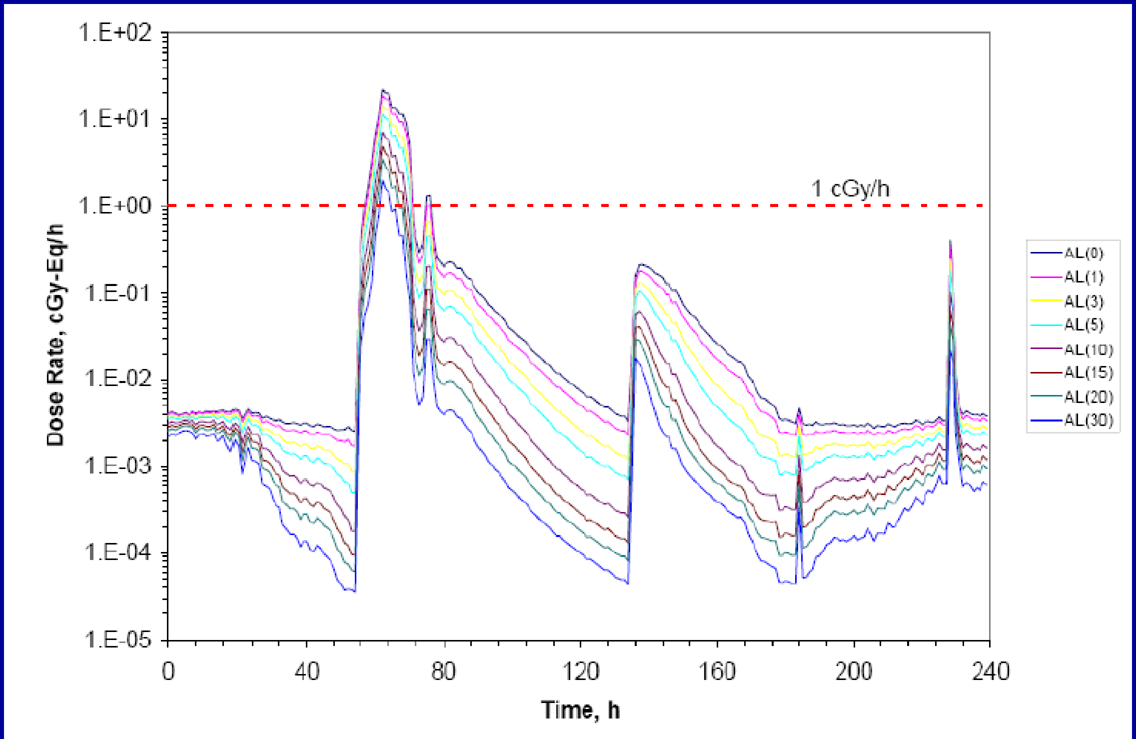
Brenner et al. Rad. Res. 1993



Cucinotta et al. 2001

- **Acute radiation risks --** Acute radiation syndromes may occur due to occupational radiation exposure

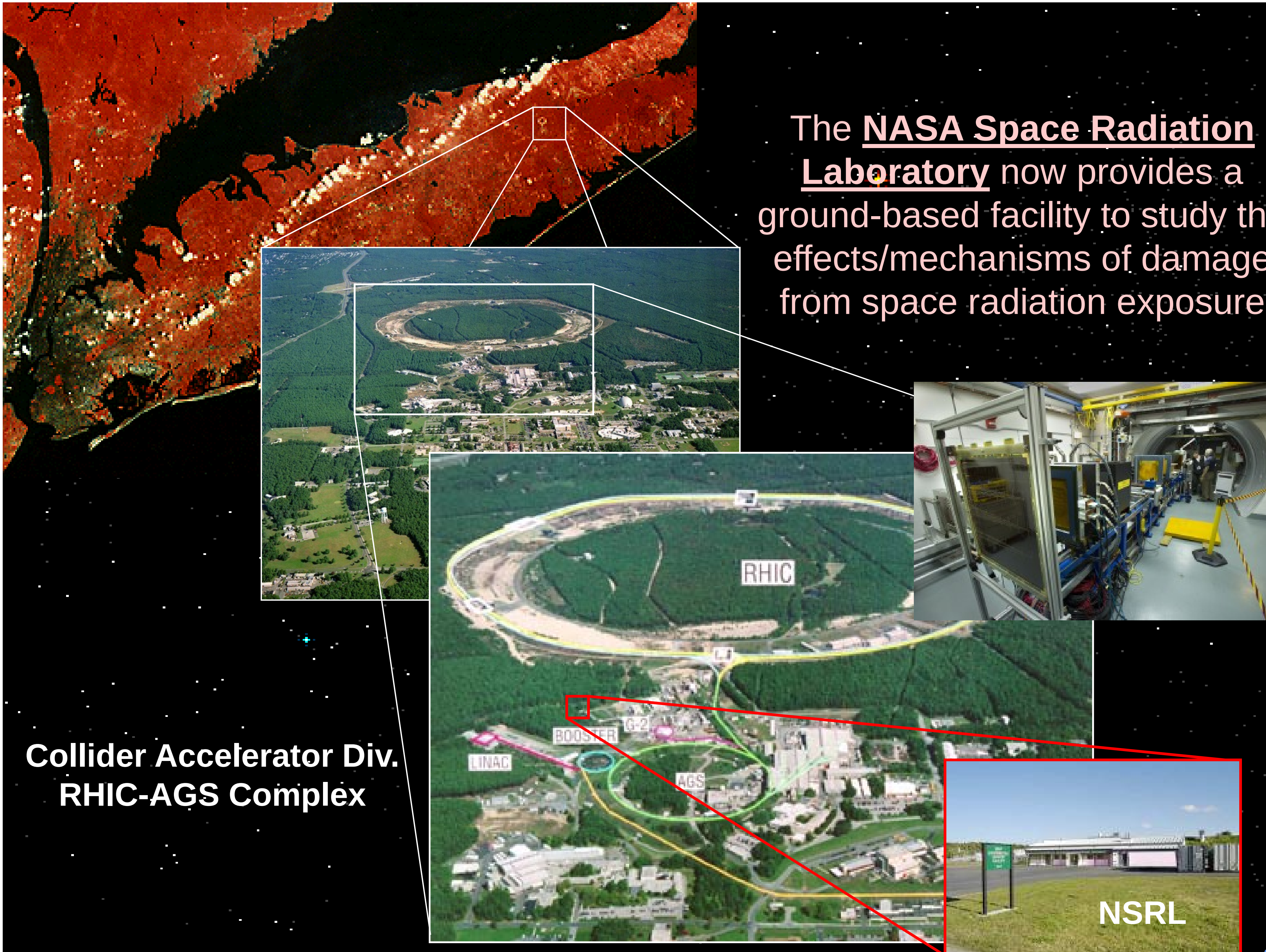
Intermediate dose rate
Kim et al. 2006



- Prodromal effect
- Skin damage
- Fatigue
- Immune function

Goals

- What are the risks from exposure to space radiation?
  - Radiation quality, dose and dose rate
  - Other spaceflight factors
- How to reduce the risks?
  - Physical
  - Biomedical



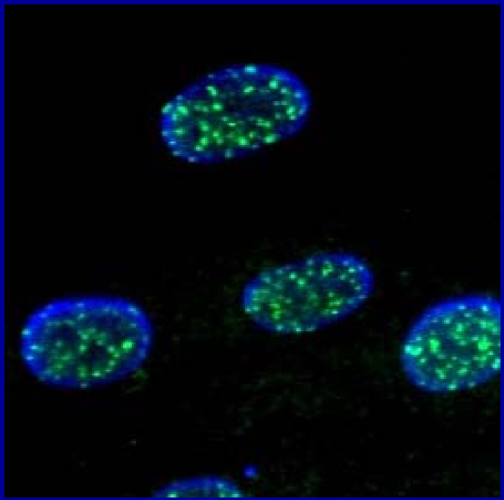
The **NASA Space Radiation Laboratory** now provides a ground-based facility to study the effects/mechanisms of damage from space radiation exposure

Collider Accelerator Div.
RHIC-AGS Complex

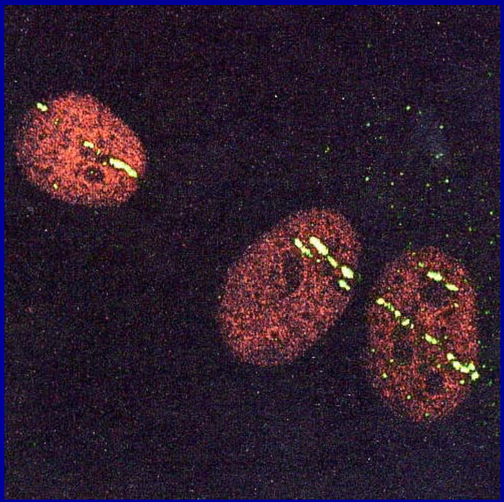
Challenges in space radiation risk assessment: Risks due to space radiation exposure can be different from those due to exposures to gamma or X-rays

DSB induction

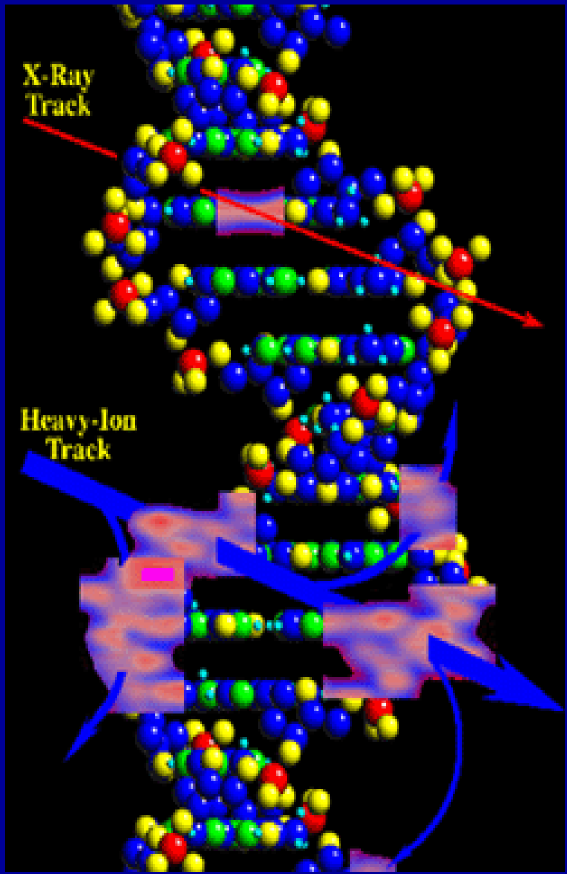
Low-LET
X-rays
Gamma rays



High-LET
Space radiation



Severity of DSB



DSB: Double strand break

Assessing the risks from space radiation exposure

Gamma/X ray (low-LET) exposure to human at high dose and high dose rate → Charged particle (High-LET) exposure to human at low dose and low dose rate

$$R(\text{High LET, LD, LDR}) = \sum \frac{R(\text{Low LET, HD, HDR}) \times Q(\text{LET})}{DDREF(\text{LET})}$$

Gamma/X ray (low-LET) exposure to human cells/animals → Charged particle (High-LET) exposure to human cells/animals

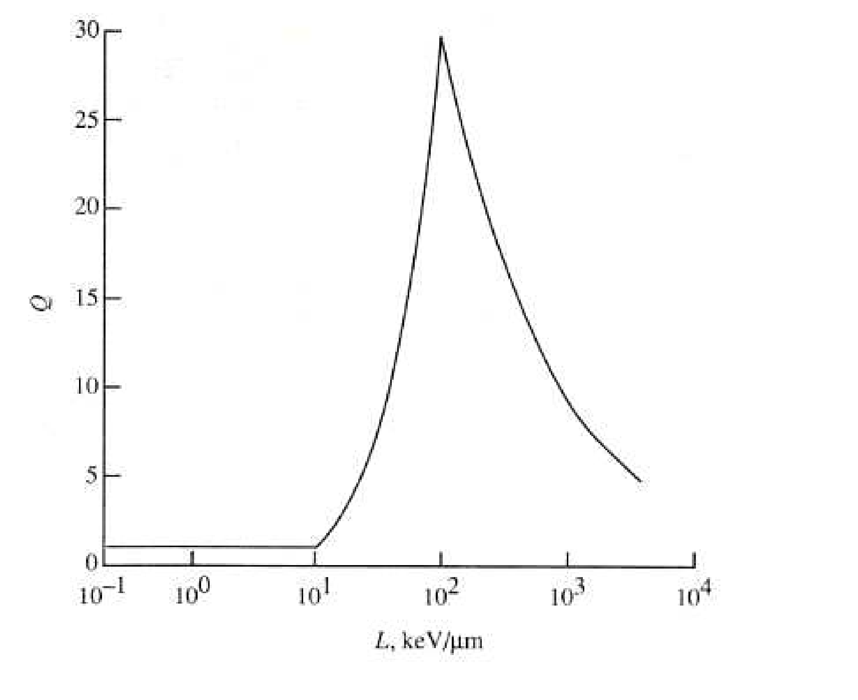
↓

Q(LET)

DDREF(LET)

for cells/animals

The quality factor can be cancer type specific



Quality factor

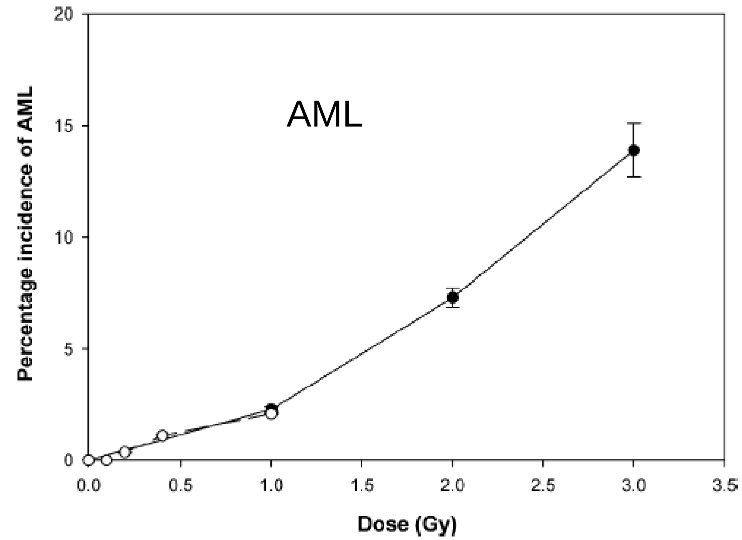


FIG. 1. Percentage incidence of AML (±SE) as a function of dose after exposure to ^{137}Cs γ rays (solid circles) or 1 GeV/nucleon ^{56}Fe ions (open circles).

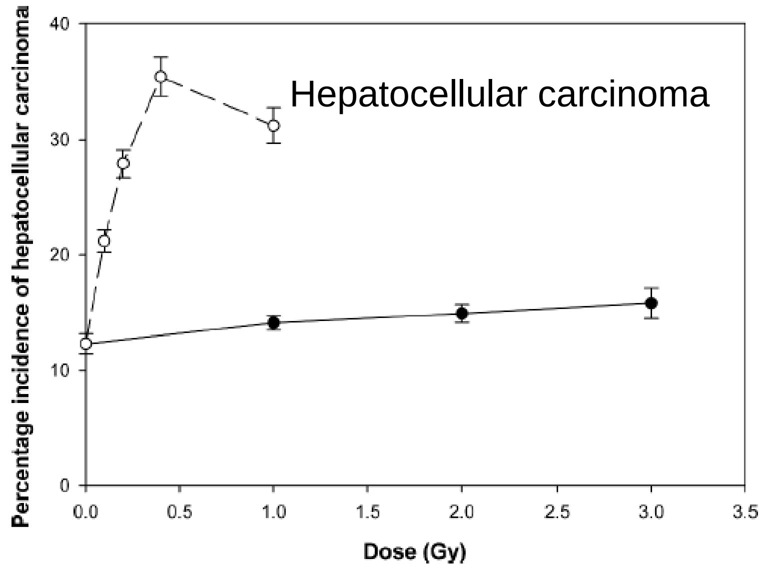
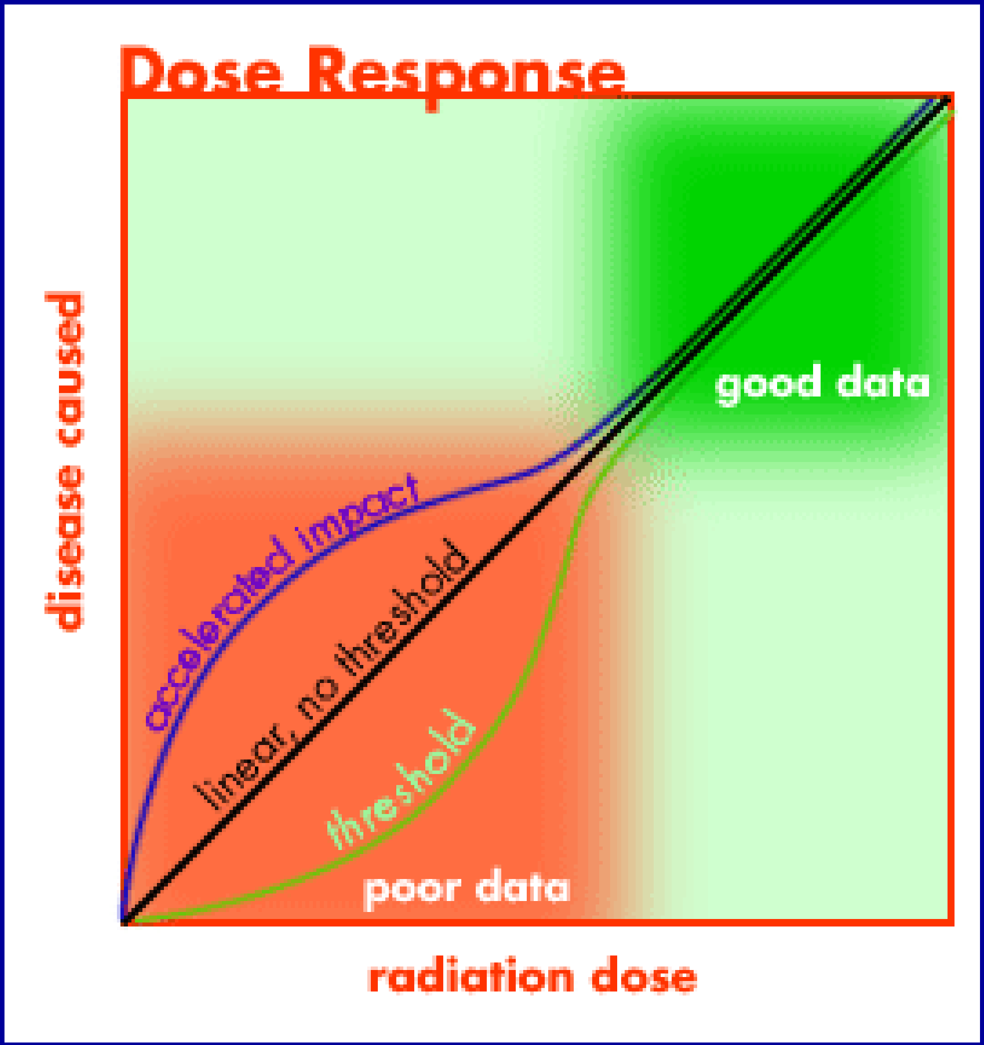


FIG. 2. Percentage incidence of hepatocellular carcinoma as a function of dose after exposure to ^{137}Cs γ rays (solid circles) or 1 GeV/nucleon ^{56}Fe ions (open circles).

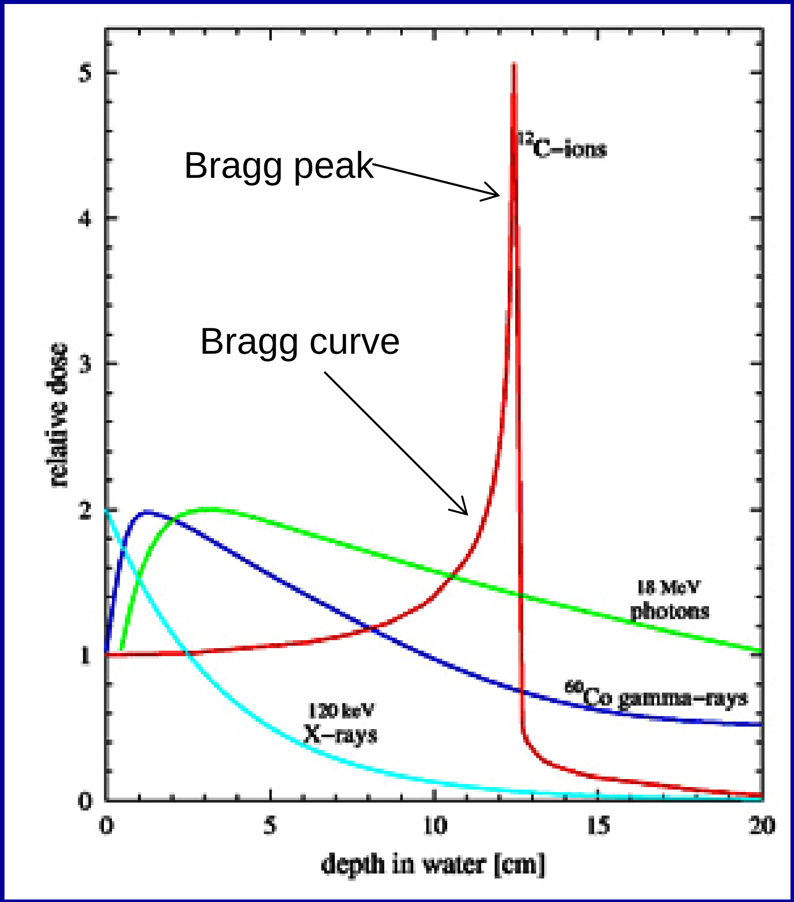
Weil et al. 2009

Challenges in space radiation risk assessment: The doses are low



- Japanese atomic bomb survivals
- Chernobyl nuclear power plan accident
- Radiation workers
- Others

Challenges in radiation protection with shielding



Dose-depth relationship
(Bragg curve)

Shielding for heavy ions generates secondary particles including neutrons

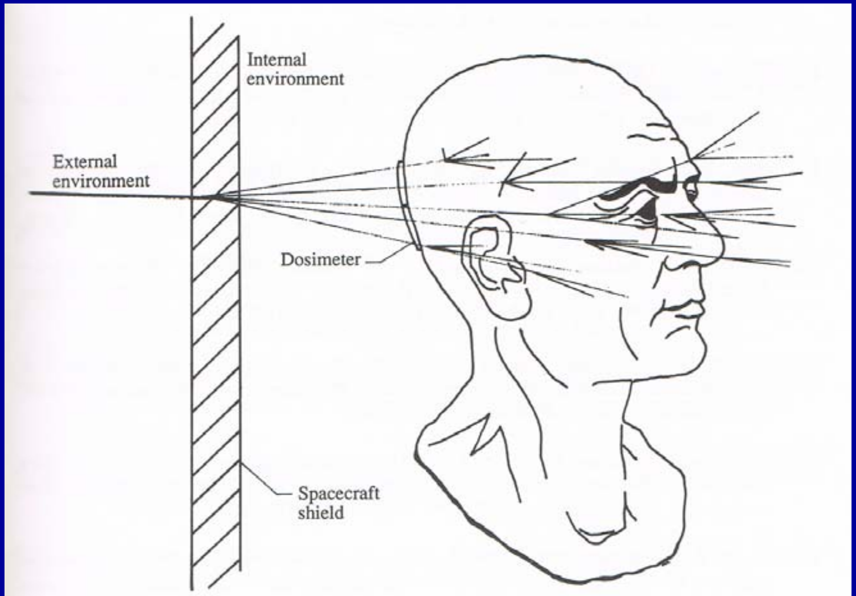


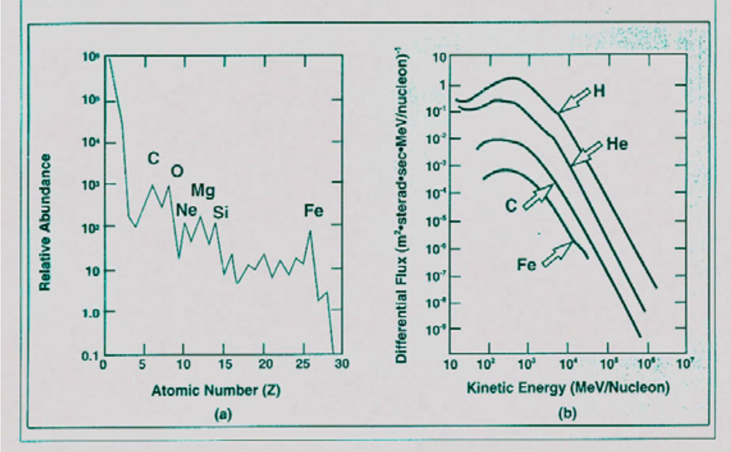
Figure 1.19. Schematic of space-radiation-protection problem.

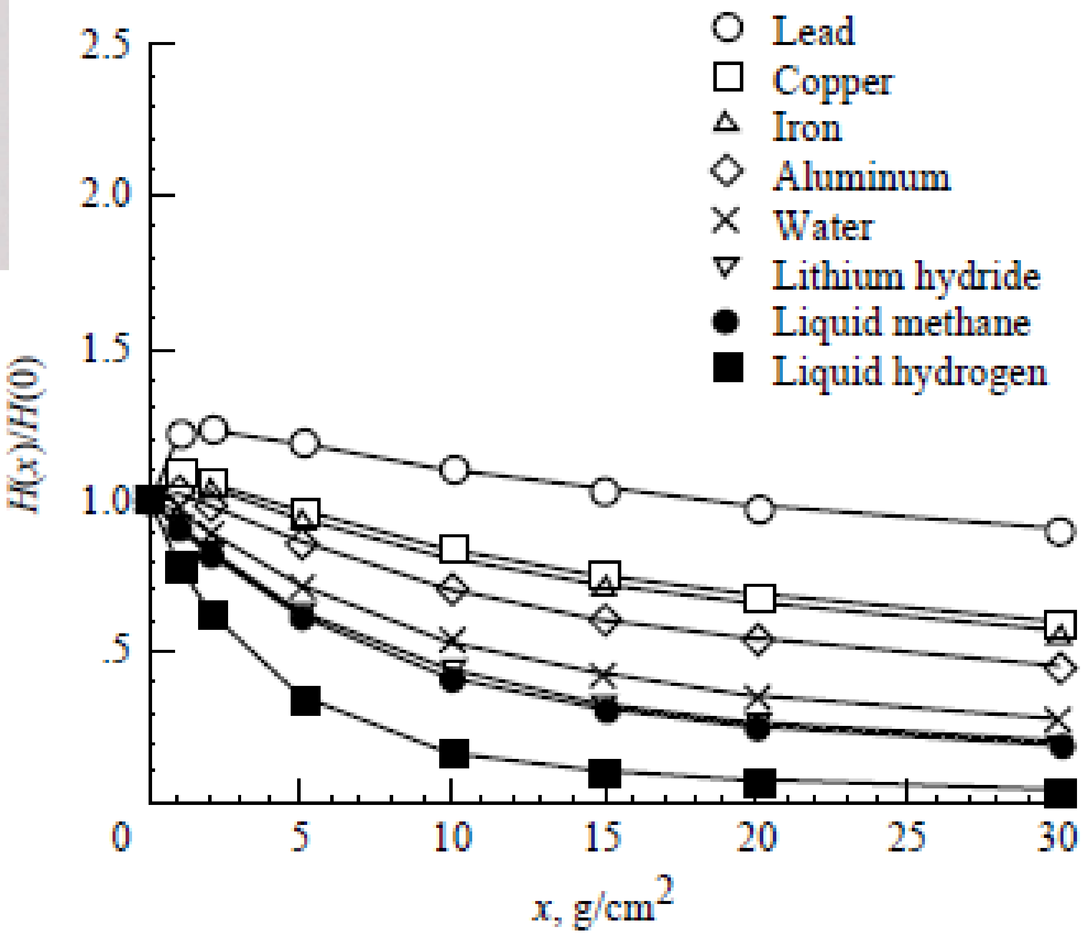
Wilson et al.

Effectiveness of shielding for GCR exposures

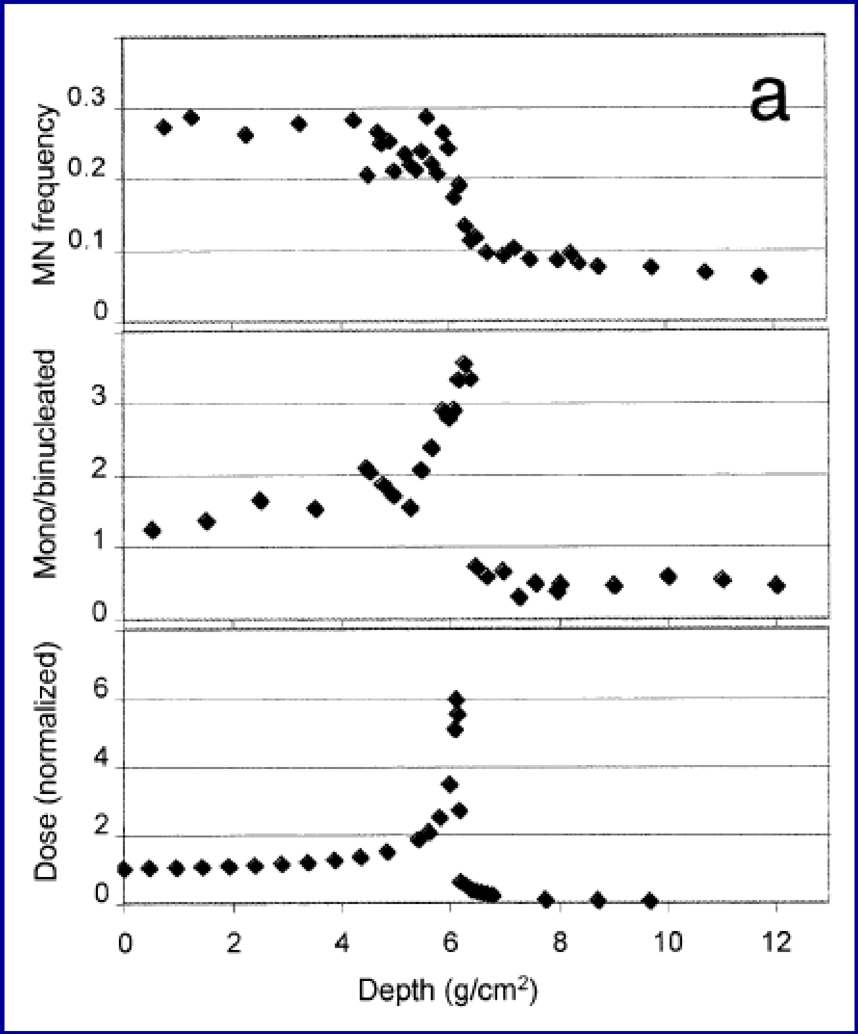
Wilson et al 2001

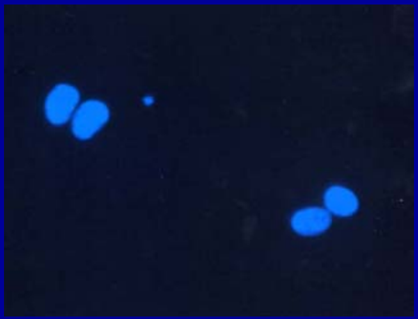
Figure D.1. Abundances (a) and Energy Spectra (b) of GCR





Dose and dose equivalent may not acurately predict biological damages around the Bragg peak





Wu et al. 2006

Challenges in Biomedical Countermeasures

- Drugs used on patients undergoing radiotherapy
  - e.g., Amifostine

- Dietary supplements
  - e.g., Vitamin A

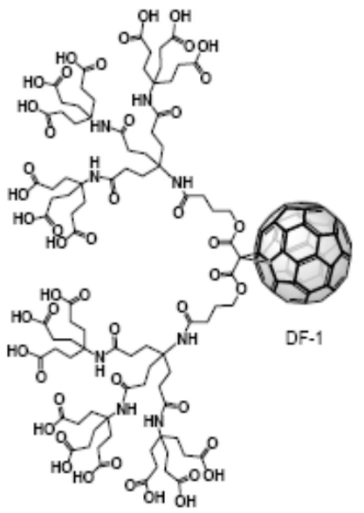
- New developments
  - e.g., Nanoparticles

Radiat Environ Biophys
DOI 10.1007/s00411-010-0296-y

ORIGINAL PAPER

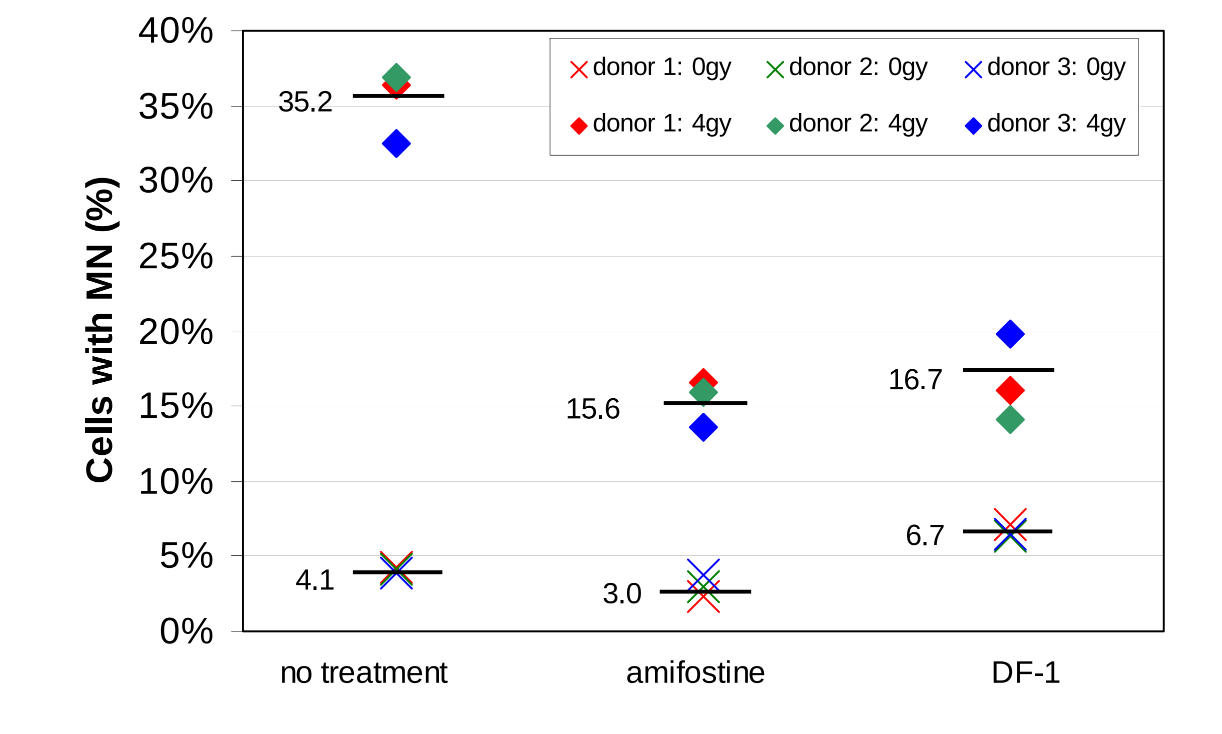
Dendro[C_{60}]fullerene DF-1 provides radioprotection to radiosensitive mammalian cells

Corey A. Theriot · Rachael C. Casey · Valerie C. Moore · Linsey Mitchell ·
Julia O. Reynolds · Madeline Burgoyne · Ranga Partha · Janice L. Huff ·
Jodie L. Conyers · Antony Jeevarajan · Honglu Wu

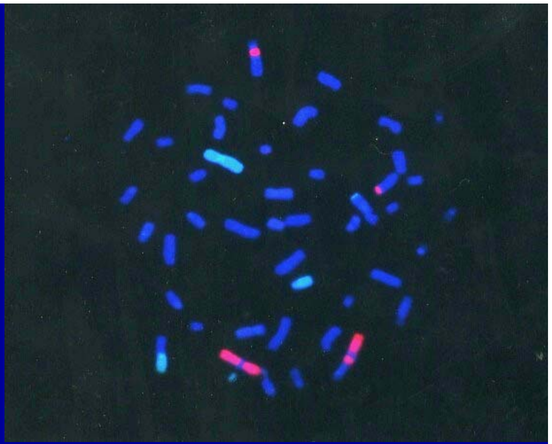


C60 fullerene DF1

DF-1 protects against 150 MeV proton-induced micronucleus formation in human lymphocytes

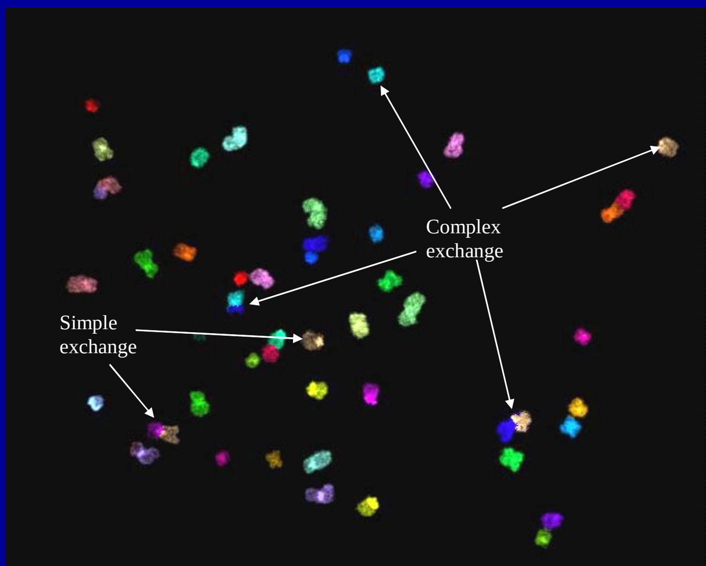


Biodosimetry



- What is biodosimetry?
  - The use of biological markers to estimate radiation exposure and dose
- Why do you need biodosimetry?
  - Complement the measurement using physical dosimeters
  - Take into account the individual susceptibility
  - Take into account the self-shielding of the body
  - Take into account the possible synergistic effect of other spaceflight factors
  - Hopefully use as a marker to predict risk
- What are the methods for biodosimetry?
  - Chromosome aberrations in astronauts' blood cells
  - Other biological markers

Biodosimetry



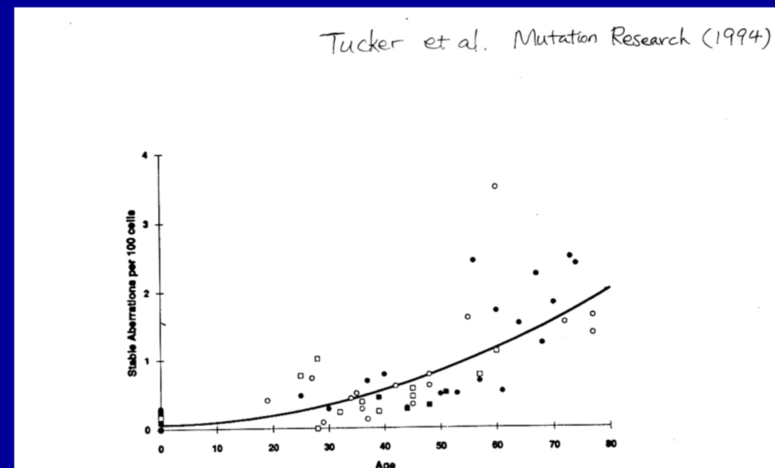
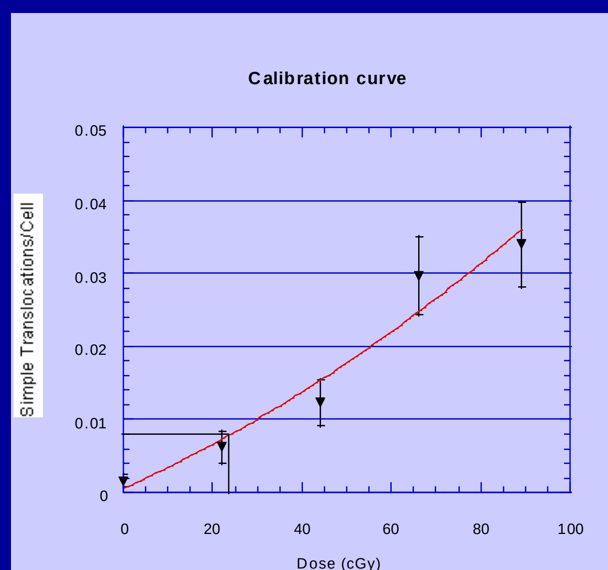
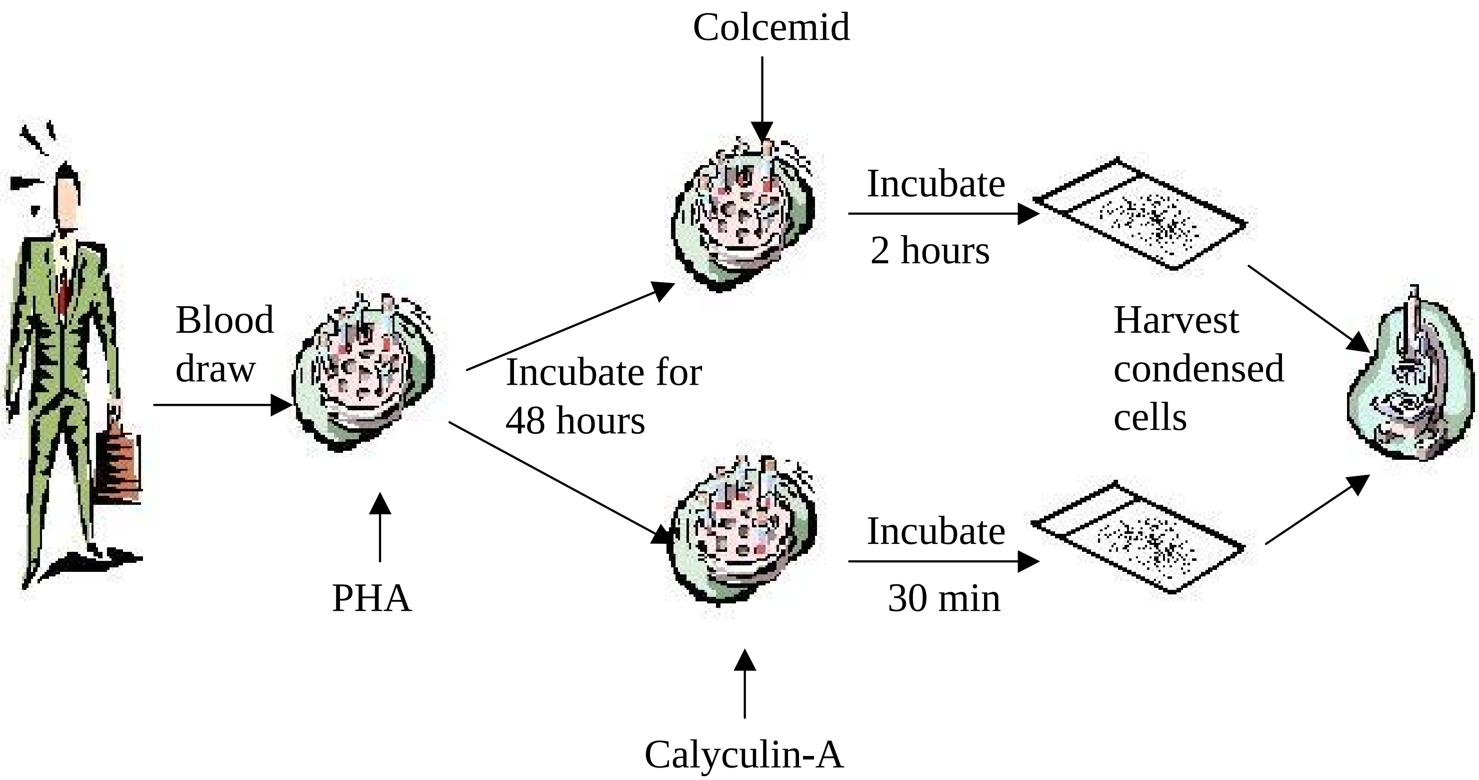


Fig. 3. The frequency of stable aberrations by age. Circles and squares represent females and males, respectively; filled and open symbols represent smokers (both previous and current) and nonsmokers, respectively. The solid line represents the least-squares regression fit to the data, as described in Statistical methods.



Biodosimetry procedure



George, Durante, Wu, Willingham, Badhwar and Cucinotta, Rad Res 2001

Frequencies of Chromosome Aberrations Measured before and after Flight for Six Crew Members of Long-Duration Mir Missions (1–6), and for Two Crew Members (7 and 8) before and after a 10-Day Shuttle Mission

				Apparent simple translocations		Complex exchanges	
Crew member	Sample collection	Cells scored	Chromosomes analyzed	No.	Frequencies ± SD ($\times 10^{-3}$)	No.	Frequencies ± SD ($\times 10^{-3}$)
1	Before flight	4404	1 + 2	19	4.3 ± 1.0	1	0.2 ± 0.2
	10 days after flight	6556	1 + 2	27	4.1 ± 0.8	7	1.1 ± 0.4
2	Before flight	1892	1, 2 + 4	5	2.6 ± 1.2	1	0.5 ± 0.5
	12 days after flight	4677	2 + 1	20	4.3 ± 1.0	2	0.4 ± 0.4
3	Before flight	3995	2 + 4	4	1.0 ± 0.5	0	0
	Day of return	4056	2 + 4	9	2.2 ± 0.7	2	0.5 ± 0.3
	240 days after flight	4745	2 + 1	14	2.9 ± 0.8	2	0.4 ± 0.3
4	Before flight	3792	2 + 4	12	3.2 ± 0.9	3	0.8 ± 0.5
	9 days after flight	4843	2 + 4	30	6.2 ± 1.1	3	0.6 ± 0.4
	114 days after flight	3604	2 + 4	20	5.5 ± 1.2	0	0
5	Before flight	742	2 + 4	3	4.0 ± 2.3	2	2.7 ± 1.9
	9 days after flight	2630	2 + 4	19	7.2 ± 1.7	0	0
6	Before flight	2852	2 + 4	7	2.4 ± 0.9	1	0.4 ± 0.4
	Day of return	4672	2 + 4	26	5.6 ± 1.1	1	0.2 ± 0.2
	9 days after flight	3147	2 + 4	13	4.1 ± 1.1	1	0.3 ± 0.3
7	Before flight	2962	1, 2 + 5	5	1.7 ± 0.7	1	0.3 ± 0.3
	Day of return	4287	1, 2 + 5	7	1.6 ± 0.6	1	0.2 ± 0.2
8	Before flight	712	1, 2 + 5	1	1.4 ± 1.4	0	0
	Day of return	2529	1, 2 + 5	4	1.6 ± 0.8	0	0

Summary

- Space radiation health risks include carcinogenesis, CNS, degenerative tissue and acute radiation
- Accurate assessment of health risks from space radiation exposure is a highly complex task
- Both physical and biological countermeasures are non-trivial issues
- The JSC Biophysics Laboratory provides operational support by evaluating the biological dose received by the astronauts during long-duration missions

Thank you!