Space Radiation

Honglu Wu, Ph.D.

NASA Johnson Space Center
Discovery of X-rays
Wilhelm Roentgen (1845-1923)
Radiation 101

• Non ionizing radiation – Microwaves, UV, laser and etc.
• Ionizing radiation – X-rays, alpha, beta and gamma radiation
• Energetic particles – Charged particles and neutrons
Radiation 101 (continue)
Space radiation is composed of energetic charged particles (atoms with all of the electrons stripped).

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.
Van Allen Belt (Trapped radiation)

James Van Allen (1914 - )

Energy spectrum of trapped protons
Origin of cosmic rays
Solar particle event (Aurora)
Inclination = 51.6 deg.
Altitude ~ 385 km.
November 2, 1997 - November 4, 1997

NASA-MIR 6 - Radiation Dosage
TEPC- PRIRODA

0 nGy/min 6500
Neutrons
Summary of space radiation environment

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

• Radiation type: Protons and heavy ions (high-LET)

• Energy of interest: 100 MeV/u ~10000 MeV/u

• Secondary neutrons

• Small amount of other types of radiation

• Ultraviolet radiation
Ultraviolet radiation

- Skin cancer and damages to the eye
- Most of the spacecraft windows are coated with UV blockers
- EVA visors are coated with UV blockers
- EVA suit has a layer of material to block UV

Ultraviolet (UV) photons harm the DNA molecules of living organisms in different ways. In one common damage event, adjacent bases bond with each other, instead of across the “ladder.” This makes a bulge, and the distorted DNA molecule does not function properly.
DNA damage from ionizing radiation
DNA strand breaks
<table>
<thead>
<tr>
<th>Mission</th>
<th>Altitude (nm)</th>
<th>Inc. (deg)</th>
<th>Duration (days)</th>
<th>Dose (cSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gemini</td>
<td>245</td>
<td>30</td>
<td>4-14</td>
<td>0.05</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td></td>
<td></td>
<td>1.22</td>
</tr>
<tr>
<td>Apollo</td>
<td>206</td>
<td>50</td>
<td>28-84</td>
<td>7.2</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td></td>
<td></td>
<td>0.27</td>
</tr>
<tr>
<td>Skylab</td>
<td>160</td>
<td>28.5</td>
<td>8.9</td>
<td>2.1</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td></td>
<td></td>
<td>10.1</td>
</tr>
<tr>
<td>STS-94</td>
<td>310</td>
<td>28.5</td>
<td>51.6</td>
<td>3.5 mo.</td>
</tr>
<tr>
<td>STS-95</td>
<td>190</td>
<td>28.5</td>
<td>3.5 mo.</td>
<td>10.1</td>
</tr>
<tr>
<td>Shuttle-Mir</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Radiation in our daily life (cSv)

- Chest X-ray: 0.002
- Lumbar spine X-rays: 0.13
- Barium enema: 0.7
- CT abdomen: 0.8
- Living in Houston for one year: 0.09
- Living in Denver for one year: 0.3

One Transcontinental round trip flight - 5 mRem (0.005 cSv)
Acute radiation syndrome

- Vomiting
- Diarrhea
- Reduction in the number of blood cells
- Bleeding
- Hair loss
- Temporary sterility in males
- Lens opacity
- Others
Acute radiation syndrome (continue)
Space Radiation Health Project

- What are the risks from exposure to space radiation?
- How to reduce the risks?
Identified Space Radiation Risks

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

- **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.

- **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.

- **Acute radiation risks** -- Acute radiation syndromes may occur due to occupational radiation exposure.
Space Radiation Protection

- ALARA (As Low As Reasonably Achievable) principle
- Radiation exposure limits

<table>
<thead>
<tr>
<th>Exposure Interval</th>
<th>Blood Forming Organs</th>
<th>Eye</th>
<th>Skin</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Days</td>
<td>25 cSv</td>
<td>100 cSv</td>
<td>150 cSv</td>
</tr>
<tr>
<td>Annual</td>
<td>50 cSv</td>
<td>200 cSv</td>
<td>300 cSv</td>
</tr>
<tr>
<td>Career</td>
<td>150 - 400 cSv [200 + 7.5(age - 30) for men]</td>
<td>400 cSv</td>
<td>600 cSv</td>
</tr>
<tr>
<td></td>
<td>100 - 300 cSv [200 + 7.5(age - 38) for women]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The dose limit for terrestrial radiation workers is 5 cSv per year.
Space radiation monitoring

- Absorbed dose
- Dose equivalent (LET)
- Charged particle type and energy
- Neutron
What are the evident biological effects of space radiation in astronauts?
# Mortality

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astronauts (N=312)</td>
<td></td>
</tr>
<tr>
<td>Spacecraft Accidents</td>
<td>14</td>
</tr>
<tr>
<td>Other Accidents</td>
<td>12</td>
</tr>
<tr>
<td>Cancer</td>
<td>5</td>
</tr>
<tr>
<td>CVD/CHD</td>
<td>3</td>
</tr>
<tr>
<td>Other/Unknown</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

Numbers provided by Mary Wear
Light Flashes

- **STAR** (Single light point)
- **DOUBLE STAR** (Double light points)
- **TADPOLE** (Tear drop shaped)
- **CLOUD** (Diffuse)
- **SNOW** (More than five short streaks)

**Light Flash Forms**

- **SHORT STREAK** (Thin line of light)
- **LONG STREAK** (Wide line of light)
- **HOT DOG** (Wide line of light)
- **DOUBLE STREAK**
- **SUPERNova** (Very bright flash)
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.
Cataract

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.

Cucinotta et al. 2001

Chromosome aberrations observed in astronauts’ lymphocytes
mFISH Analysis

Simple exchange

Complex exchange
Conclusions

- Astronauts receive the highest occupational radiation exposure

- Effective protections are needed to ensure the safety of astronauts on long duration space missions