Radiation Physiology and Effects

- Sources and types of space radiation
- Effects of radiation
- Shielding approaches
## The Electromagnetic Spectrum

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Wavelength (m)</th>
<th>Wavelength (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{22}$</td>
<td>$10^{-13}$</td>
<td>Shortest Visible Blue (0.4)</td>
</tr>
<tr>
<td>$10^{18}$</td>
<td>$10^{-10}$</td>
<td>Green (0.5)</td>
</tr>
<tr>
<td>$10^{14}$</td>
<td>$10^{-7}$</td>
<td>Yellow (0.6)</td>
</tr>
<tr>
<td>$10^{13}$</td>
<td>$10^{-6}$</td>
<td>Orange (0.7)</td>
</tr>
<tr>
<td>$10^{10}$</td>
<td>$10^{-3}$</td>
<td>Longest Visible Red (0.8)</td>
</tr>
<tr>
<td>$10^{7}$</td>
<td>$10^{1}$</td>
<td></td>
</tr>
<tr>
<td>$10^{4}$</td>
<td>$10^{4}$</td>
<td></td>
</tr>
</tbody>
</table>

The Solar Spectrum

The Earth’s Magnetic Field

The Van Allen Radiation Belts

Cross-section of Van Allen Radiation

Electron Flux in Low Earth Orbit

The Origin of a Class X1 Solar Flare

Approximate size of earth for comparison
Heavy Ion Flux

Background

Ref: Neville J. Barter, ed., TRW Space Data, TRW Space and Electronics Group, 1999

Solar Flare
Radiation Units

- **Dose** $D =$ absorbed radiation
  
  \[ 1 \text{ Gray} = 1 \frac{\text{Joule}}{\text{kg}} = 100 \text{ rad} = 10,000 \frac{\text{ergs}}{\text{gm}} \]

- **Dose equivalent** $H =$ effective absorbed radiation
  
  \[ 1 \text{ Sievert} = 1 \frac{\text{Joule}}{\text{kg}} = 100 \text{ rem} = 10,000 \frac{\text{ergs}}{\text{gm}} \]

  \[ H = D \times Q \]
  \[ \text{rem} = RBE \times \text{rad} \]

- **LET** = Linear Energy Transfer \(<\text{KeV/}\mu\text{m}>\)
### Radiation Quality Factor

<table>
<thead>
<tr>
<th>Radiation</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-rays</td>
<td>1</td>
</tr>
<tr>
<td>5 MeV γ-rays</td>
<td>0.5</td>
</tr>
<tr>
<td>1 MeV γ-rays</td>
<td>0.7</td>
</tr>
<tr>
<td>200 KeV γ-rays</td>
<td>1.0</td>
</tr>
<tr>
<td>Electrons</td>
<td>1.0</td>
</tr>
<tr>
<td>Protons</td>
<td>2-10</td>
</tr>
<tr>
<td>Neutrons</td>
<td>2-10</td>
</tr>
<tr>
<td>α-particles</td>
<td>10-20</td>
</tr>
<tr>
<td>GCR</td>
<td>20+</td>
</tr>
</tbody>
</table>

**Graph:**
- ICRP 26 until 1990
- ICRP 60 since 1990

**LET (Tissue) [keV/µm]**

**Quality-Factor**
Radiation in Free Space

![Graph showing radiation sources and energy levels](image-url)
Radiation Dose vs. Orbital Altitude

300 mil (7.6 mm) Al shielding

Ref: Neville J. Barter, ed., TRW Space Data, TRW Space and Electronics Group, 1999
Dosage Rates from Oct/Nov 2003 SPE

![Graph showing dosage rates over time. The graph has a logarithmic scale on the y-axis and a linear scale on the x-axis. Peaks in dosage rate are visible at various times, and the graph includes a horizontal line at 1 rem/h as a reference.]
SPEs in Solar Cycles 19, 20, and 21
GCR Constituent Species

![Graph showing the relative abundance of different atomic species](image-url)
Solar Max/Min GCR Proton Flux Ratio

![Graph showing the Solar Max/Min GCR Proton Flux Ratio against kinetic energy in MeV. The graph depicts a cycle with a minimum at around 10^2 MeV and a peak at around 10^5 MeV.]
Radiation Damage to DNA
Damage Tracks of $\gamma$ and Heavy Ion (GCR)
Symptomology of Acute Radiation Exposure

- “Radiation sickness”: headache, dizziness, malaise, nausea, vomiting, diarrhea, lowered RBC and WBC counts, irritability, insomnia
- 50 rem (0.5 Sv)
  - Mild symptoms, mostly on first day
  - ~100% survival
- 100-200 rem (1-2 Sv)
  - Increase in severity and duration
  - 70% incidence of vomiting at 200 rem
  - 25%-35% drop in blood cell production
  - Mild bleeding, fever, and infection in 4-5 weeks
Symptomology of Acute Radiation Exposure

- **200-350 rem (2-3.5 Sv)**
  - Earlier and more severe symptoms
  - Moderate bleeding, fever, infection, and diarrhea at 4-5 weeks

- **350-550 rem (3.5-5.5 Sv)**
  - Severe symptoms
  - Severe and prolonged vomiting - electrolyte imbalances
  - 50-90% mortality from damage to hematopoietic system if untreated
Symptomology of Acute Radiation Exposure

• 550-750 rem (5.5-7.5 Sv)
  - Severe vomiting and nausea on first day
  - Total destruction of blood-forming organs
  - Untreated survival time 2-3 weeks

• 750-1000 rem (7.5-10 Sv)
  - Survival time ~2 weeks
  - Severe nausea and vomiting over first three days
  - 75% prostrate by end of first week

• 1000-2000 rem (10-20 Sv)
  - Severe nausea and vomiting in 30 minutes

• 4500 rem (45 Sv)
  - Survival time as short as 32 hrs - 100% in one week
Long-Term Effects of Radiation Exposure

• Radiation carcinogenesis
  - Function of exposure, dosage, LET of radiation

• Radiation mutagenesis
  - Mutations in offspring
  - Mouse experiments show doubling in mutation rate at 15-30 rad (acute), 100 rad (chronic) exposures

• Radiation-induced cataracts
  - Observed correlation at 200 rad (acute), 550 rad (chronic)
  - Evidence of low onset (25 rad) at high LET
Radiation Carcinogenesis

- **Manifestations**
  - Myelocytic leukemia
  - Cancer of breast, lung, thyroid, and bowel

- **Latency in atomic bomb survivors**
  - Leukemia: mean 14 yrs, range 5-20 years
  - All other cancers: mean 25 years

- **Overall marginal cancer risk**
  - 70-165 deaths/million people/rem/year
  - 100,000 people exposed to 10 rem (acute) -> 800 additional deaths (20,000 natural cancer deaths) - 4%
NASA Radiation Dose Limits

NCRP-132 (2000)

- NCRP-132 (Male)
- NCRP-132 (Female)

10 Year Career Exposure Limits (Sv)

Age (yrs.):
- 25
- 35
- 45
- 55

Sv:
- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3
- 3.5
- 4

Radiation Physiology and Effects
ENAE 697 -Space Human Factors and Life Support
Density of Common Shielding Materials

- Polyethylene
- Water
- Gr/Ep
- Acrylics
- Aluminum
- Lead
Comparative Thickness of Shields (Al=1)
Comparative Mass for Shielding (Al=1)
Shielding Requirements

- Reduce severe SPE to 0.25 Sv - 8 gm(Al)/cm²
- Reduce severe SPE to 0.12 Sv - 18 gm(Al)/cm²
- Reduce GCR to 0.25 Sv/yr - 8 gm(Al)/cm²
- Reduce GCR to 0.12 Sv/yr - 50 gm(Al)/cm²
- Lunar base - recommend 50 gm(regolith)/cm²
- Mars mission - 20 gm/cm²
  - 7.5 cm of aluminum
  - 2 m diameter sphere -> 2500 kg