Painting analysis of chromosome aberrations induced by energetic heavy ions in human cells

Honglu Wu, Ph.D.
NASA Johnson Space Center
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.
Galactic cosmic radiation

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

High-LET

Low-LET
Radiation-induced chromosome aberrations in lymphocytes in vitro

Why do we study chromosomes?

Chromosome aberrations in astronauts’ lymphocytes are analyzed to determine the biological dose received from long-term space missions

<table>
<thead>
<tr>
<th>Subject</th>
<th>TLD reading (cGy)</th>
<th>Biological dose measured using values for translocation (cSv)</th>
<th>Average RBE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.06</td>
<td>16</td>
<td>4.2</td>
</tr>
<tr>
<td>2</td>
<td>3.78</td>
<td>18</td>
<td>3.8</td>
</tr>
<tr>
<td>3</td>
<td>5.68</td>
<td>20</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>4.16</td>
<td>23</td>
<td>4.4</td>
</tr>
<tr>
<td>5</td>
<td>4.16</td>
<td>14</td>
<td>2.7</td>
</tr>
<tr>
<td>6</td>
<td>4.16</td>
<td>12</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*25% correction for high-LET radiation in TLD measurement is included.

Mission duration: 3-5 months
Altitude: 190 NM
Inclination: 51.6 degree
Objectives

• Are there bio-signatures for space radiation exposure?

• Are chromosome aberrations associated with radiation risks?
Chromosome staining/painting techniques

Giemsa

FISH

mFISH

mBAND
Chromosome aberration

Stable

Unstable

Inter-chromosome exchange

Intra-chromosome exchange
Telomere Analysis

Human lymphocytes exposed to 2.6 Gy gamma rays. Chromosomes 2 and 4 were painted.
Most of the incomplete exchanges analyzed with FISH are actually complete.

Wu, George and Yang, IJRB (1998, 1999)
Human fibroblast cells exposed to radiation of different qualities

- The fraction of unrejoined chromosome breaks are higher for high LET
- Unrejoined breaks and incomplete chromosomal exchanges are possible biosignatures of high-LET radiation

High-LET radiation induces more unrejoined DNA double strand breaks

Desai, Davis, O’Neill, Durante, Cucinotta and Wu, Rad. Res. 2005
Complex aberrations -- mFISH analysis

mFISH showed a higher fraction of complex and incomplete exchanges for high-LET.
Interphase vs. metaphase: Issues of biosignature
(F ratio: Ratio of dicentrics to centric rings)

Centromere probes were used.

<table>
<thead>
<tr>
<th>Radiation</th>
<th>Dose (Gy)</th>
<th>Harvest method</th>
<th>F ratio</th>
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</thead>
<tbody>
<tr>
<td>γ ray</td>
<td>2</td>
<td>PCC</td>
<td>15.3±6.3</td>
</tr>
<tr>
<td>γ ray</td>
<td>2</td>
<td>Meta</td>
<td>12.5±5.9</td>
</tr>
<tr>
<td>γ ray</td>
<td>5</td>
<td>PCC</td>
<td>8.2±2.0</td>
</tr>
<tr>
<td>γ ray</td>
<td>5</td>
<td>Meta</td>
<td>9.1±2.5</td>
</tr>
<tr>
<td>1 GeV/u Fe</td>
<td>3</td>
<td>PCC</td>
<td>5.2±0.9</td>
</tr>
<tr>
<td>1 GeV/u Fe</td>
<td>3</td>
<td>Meta</td>
<td>9.1±2.2</td>
</tr>
</tbody>
</table>

Wu, George, Kawata, Willingham and Cucinotta, Rad. Res. 2001
mBAND analysis

<table>
<thead>
<tr>
<th>FITC</th>
<th>SpO</th>
<th>Texas Red</th>
<th>Cy5</th>
<th>DEAC</th>
<th>DAPI</th>
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<tr>
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<td><img src="image3" alt="Normal Image" /></td>
<td><img src="image4" alt="Normal Image" /></td>
<td><img src="image5" alt="Normal Image" /></td>
<td><img src="image6" alt="Normal Image" /></td>
</tr>
<tr>
<td><img src="image1" alt="Inversion Image" /></td>
<td><img src="image2" alt="Inversion Image" /></td>
<td><img src="image3" alt="Inversion Image" /></td>
<td><img src="image4" alt="Inversion Image" /></td>
<td><img src="image5" alt="Inversion Image" /></td>
<td><img src="image6" alt="Inversion Image" /></td>
</tr>
</tbody>
</table>
Inter- vs. intra chromosome exchanges (mBAND)

![Graph showing comparisons between inter-exchange and intra-exchange aberrations in chromosome 3 per cell vs. dose (Gy). The graph includes data for $^{137}$Cs $\gamma$-ray and Fe (600 MeV/n) with error bars.]
Most inversions were involved with other inter- and/or intra-chromosome rearrangements.
Do spaceflight factors alter the cellular response to radiation exposure?

Hammond et al. Nature Medicine 1999
Chromosome aberration frequencies in pre- and post-flight astronaut lymphocytes irradiated in vitro with low-LET radiation (Wu et al. Phys. Med. 2001)

Mission: STS-103

Duration: 8 days

Blood draw schedule:
- 10 days before launch, JSC, kept at 4 C for 1 day before exposure
- 0 days after landing, KSC, kept at 4 C and received next day. Kept at 4 C before exposure
- 14 days after landing, KSC, kept at 4 C for 1 day before exposure

Irradiation: Whole blood was irradiated to gamma rays

Procedure: Whole blood was stimulated to grow with PHA in growth medium and chromosomes were collected following standard procedures.

Chromosome analysis: Chromosomes #1 and #5 were painted.
Do spaceflight factors alter the cellular response to radiation exposure?

Wu, George, Willingham and Cucinotta, Physica Medica 2001

Summary

- FISH, mFISH, mBAND, telomere and centromere probes have been used to study chromosome aberrations induced in human cells exposed to low- and high-LET radiation in vitro.

- High-LET induced damages are mostly a single track effect.

- Unrejoined chromosome breaks (incomplete exchanges) and complex type aberrations were higher for high-LET.

- Biosignatures may depend on the method the samples are collected.

- Recent mBAND analysis has revealed more information about the nature of intra-chromosome exchanges.

- Whether space flight/microgravity affects radiation-induced chromosome aberration frequencies is still an open question.