The Mars Science Laboratory (MSL) Radiation Assessment Detector (RAD)

Robert F. Wimmer-Schweingruber¹,  R. Beaujean¹, E. Böhm¹,  S. Böttcher¹,  S. Burmeister¹,  K. Herbst¹, O. Kortmann¹,  C. Martin¹,  R. Müller-Mellin¹, L. Seimetz¹,  S. Kolbe¹,  G. Reitz²,  D. Hassler³, J. Andrews³,  M. Bullock³,  D. Grinspoon³, M. Epperly³,  A. Posner³,  S. Rafkin³,  K. Smith³, F. Cuccinotta⁴,  T. Cleghorn⁴

¹Institute for Experimental und Applied Physics, CAU Kiel, Germany, ²DLR Cologne, ³Southwest Research Institute, Boulder and San Antonio, ⁴Johnson Space Center

ESWW3, Brussels, November 16, 2006
The MSL Radiation Assessment Detector (RAD)

Mars Science Laboratory (MSL)

Charged particle - matter interaction

Radiation Assessment Detector (RAD) Science

RAD Sensor Head (RSH) Design

RSH modeling and calibration results
- Exploration of a Martian region as a potential habitat ("past or present")
- Biological potential of the region
- Geology and geochemistry of the region (from $\mu$m to m)
- Identification of relevant planetary processes for habitability
- Characterisation of the broad particle spectrum on the Martian surface including neutrons and $\gamma$s $\rightarrow$ RAD
Assess a Martian Region as a Potential Habitat
MSL Payload

- Arm
  - Scoop
  - Abrader, Corer
  - APXS
  - MAHLI

- Mast-Mounted
  - ChemCam
  - MastCam
  - REMS

- Sample Processing and Distribution
  - Rock Crusher
  - Sample Observation
  - Sample Distribution

- Body Mounted
  - DAN
  - RAD
  - MARDI

- Payload Module
  - ChemMin
  - SAM
  - Warm Electronics for Mast and Contact Instruments
MSL Rover

Sojourner

MER

MSL – Dec 2004

MSL – Oct 2003
MSL Rover
Energetic charged particles ionize target material

\[ \frac{dE}{dx} \sim \frac{Z^2 \rho}{E} \ldots \text{(Bethe-Bloch)} \]
Energetic charged particles ionize target material

\[ \frac{dE}{dx} \sim \frac{Z^2 \rho}{E} \quad \text{(Bethe-Bloch)} \]

![Graph showing energy deposition over distance in air at normal pressure]
Pfotzer Maximum

at 20 km altitude on Earth,
Pfotzer Maximum

at 20 km altitude on Earth,
Pfotzer Maximum

at 20 km altitude on Earth, but at Martian surface!
Radiation Assessment Detector Science

Solar Energetic Particles

Galactic Cosmic Rays (Protons and HZE)

Atmospheric Absorption & Molecular Dissociation

Secondary Particle Production (atmosphere)

Secondary Particle Production (regolith)

DNA Damage & Mutagenesis

C14 Production & Other Nuclear Reactions
## MSL RAD Scientific Objectives

**To characterize fully the broad spectrum of radiation at the surface of Mars.**

<table>
<thead>
<tr>
<th>Radiation Assessment Detector Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characterize the energetic particle spectrum incident at the surface of Mars, including direct and indirect radiation created in the atmosphere and regolith.</td>
</tr>
<tr>
<td>Determine the radiation Dose rate and Equivalent Dose rate for humans on the Martian surface.</td>
</tr>
<tr>
<td>Validate Mars atmospheric transmission models and radiation transport codes.</td>
</tr>
<tr>
<td>Determine the radiation hazard and mutagenic influences to life, past and present, at and beneath the Martian surface.</td>
</tr>
<tr>
<td>Determine the chemical and isotopic effects of energetic particles on the Martian surface and atmosphere.</td>
</tr>
</tbody>
</table>
RAD Measurement Requirements

1. Energetic charged particles ($1 \leq Z \leq 26$) up to 100 MeV/nuc
2. Neutral particles ($\gamma$s and neutrons) up to 100 MeV
3. Electrons up to 10 MeV
4. Dose and LET spectra
5. Resolution sufficient to resolve low-$Z$ (p, He) from medium-$Z$ (C, N, O, . . .) and high-$Z$ (up to Fe) elements
6. Time resolution sufficient to resolve solar particle events
RAD Sensor Head (RSH) Implementation

Combination of telescope and calorimeter

Measure GCR, SEP, n, \( \gamma \)

Energy range:

<table>
<thead>
<tr>
<th>Particle</th>
<th>Energy Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ions</td>
<td>5 - 270 MeV/amu</td>
</tr>
<tr>
<td>( p, \alpha )</td>
<td>5 - 100 MeV/amu</td>
</tr>
<tr>
<td>( e^- )</td>
<td>150 keV - 15 MeV</td>
</tr>
</tbody>
</table>
RAD Sensor Head (RSH) Implementation

CsI crystal for $\gamma$s and as calorimeter

<table>
<thead>
<tr>
<th>Measure GCR, SEP, n, $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
</tr>
<tr>
<td>2 - 100 MeV</td>
</tr>
<tr>
<td>$\gamma$</td>
</tr>
<tr>
<td>$&gt; 1,5$ MeV</td>
</tr>
</tbody>
</table>

CsI stops 100 MeV/amu p
RAD Sensor Head (RSH) Implementation

Measure GCR, SEP, n, $\gamma$

- $n \quad 2 - 100 \text{ MeV}$
- $\gamma \quad > 1.5 \text{ MeV}$

Anti-coincidence 99.98% efficient

Neudos anticoincidence
RAD Sensor Head (RSH) modeling indicates that RAD will perform as expected.

Use Geant4 Monte-Carlo model of RSH to simulate instrument performance. Model does not yet include detector and FEE response and direct Si hits.
Detection of stopping particles

\[
dE/dx \text{ (SSD-A)} \text{ and geometry factor versus total energy deposit}
\]
Calibration shows expected results
### Expected Performance

<table>
<thead>
<tr>
<th>radiation (particle)</th>
<th>count rate (per second)</th>
<th>uncertainty (%/6 months)</th>
<th>model uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>0.25</td>
<td>0.1</td>
<td>20%</td>
</tr>
<tr>
<td>e</td>
<td>0.02</td>
<td>0.35</td>
<td>20%</td>
</tr>
<tr>
<td>CNO</td>
<td>(5 \times 10^{-3})</td>
<td>0.7</td>
<td>20%</td>
</tr>
<tr>
<td>Fe</td>
<td>(3 \times 10^{-4})</td>
<td>3</td>
<td>20%</td>
</tr>
<tr>
<td>n</td>
<td>20 – 200</td>
<td>0.25 – 0.75</td>
<td>100%</td>
</tr>
<tr>
<td>dosimetry</td>
<td>25</td>
<td>0.7 (per hour)</td>
<td>–</td>
</tr>
</tbody>
</table>
Conclusions

RSH will determine the broad spectrum of surface radiation using a novel combination of detection techniques.
Backup Slides
Neutron and $\gamma$ background from RTG and DAN

**Neutron Energy Spectrum for Qualification RTG (Ulysses Mission)**

**Source Q1 at Mound Laboratories (DoE), 1984**
- measured at $\theta = 90^\circ$ and $522 \text{ cm}$ from source axis
- normalized so that area under the curve is unity
- average energy $<E> = 1.64 \pm 0.07 \text{ MeV}$

**Spectrum is as expected for a source with neutrons from**
- $^{239}$Pu($,n$) reaction
- spontaneous fission
- neutron induced fission

**Total neutron emission rate on August 29, 1984:**
$(4.5 \pm 0.4) \times 10^7 \text{ n/s}$

**Specific neutron emission rate on August 29, 1984:**
$5900 \text{ n/s/g}^{238}\text{Pu}$

**Factor for converting from neutron fluence to:**
- **dose equivalent:** $(3.1 \pm 0.24) \times 10^3 \text{ mRe/n-cm}^2$
- **tissue absorbed dose:** $(3.18 \pm 0.26) \times 10^{-6} \text{ mRad/n-cm}^2$
Neutron and $\gamma$ background from RTG and DAN
Neutron and $\gamma$ background from RTG and DAN

Neutrons and gamma-rays from Mars may be also produced by Pulsing Neutron Generator
Statistical neutron and $\gamma$ separation

Detected energy vs particle energy matrix

![Plot showing energy distributions](image_url)
Detection of penetrating particles

Energy loss and geometry factor of penetrating charged particles

- E(AC) > 1.5 MeV
- E(neutron) > 1 MeV
- E(Csl) > 10 MeV
- E(AC) > 0.07 * E(Csl)
- E(AC) < E(Csl)
- E(SSD) > 60 keV
- E(SSD) > 0.2 * [E(A) + E(B) + E(C)]
- min(E(SSD)) > 0.0035 * E(Csl)

p, e-, He, Li, Be, O, Si, Ca, Fe
## MSL/RAD-Institutions

<table>
<thead>
<tr>
<th>Institution</th>
<th>PI-Institution</th>
<th>Lead-Col Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Southwest Research Institute</strong></td>
<td>Don Hassler, PI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Project management</td>
<td>Sensorhead, FEE</td>
</tr>
<tr>
<td></td>
<td>Electronics</td>
<td>data analysis</td>
</tr>
<tr>
<td></td>
<td>Geology, atmosph. transport</td>
<td>Modeling</td>
</tr>
<tr>
<td></td>
<td>Astrobiology</td>
<td></td>
</tr>
<tr>
<td><strong>University of Kiel</strong></td>
<td>Bob Wimmer, Lead-Col</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calibration, Dosimetry</td>
<td>Astronaut Safety</td>
</tr>
<tr>
<td></td>
<td>Astronaut Safety</td>
<td></td>
</tr>
<tr>
<td><strong>DLR Cologne</strong></td>
<td>Günther Reitz, Lead-Col</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Johnson Space Flight Center</strong></td>
<td>Frank Cuccinotta, Lead-Col</td>
<td></td>
</tr>
</tbody>
</table>