Initial Results from the Radiation Dosimetry Experiment (RaD-X) Balloon Flight Mission

Dr. Christopher J. Mertens
Principal Investigator, RaD-X
NASA Langley Research Center
Hampton, Virginia USA
Outline

- **Research Motivation**
  - Aviation Radiation Health Effects
  - Aviation Radiation Avionic Effects
  - NAIRAS Model Development

- **Cosmic Ray Basics**
  - Sources
  - Energy and Composition
  - Atmospheric Interactions
  - Biological Interactions

- **Dosimetric Quantities**
  - Definitions
  - Range of Values @ Flight Altitude

- **NAIRAS Model**
  - Representative Data Products
  - Variation With Solar Cycle and Geomagnetic Cutoff Rigidity
  - Solar and Geomagnetic Storm Effects

- **RaD-X Science**
  - Motivation (in more detail)
  - Science Goals and Objectives
  - Instrument Selection
The NAIRAS model currently underestimates actual data. This performance is quantified by comparisons with recent DLR-TEPC/Liulin measurements from 2008 [Mertens et al., 2013]

- These results are consistent with the large volume of data reported by Lindborg et al. [2004] and tabulated by the International Commission on Radiation Units and Measurements: ICRU Report 84 [2010]

- The NAIRAS/DLR/ICRU comparisons in publication [Mertens et al., 2013]
NAIRAS Comparisons to Existing Measurements

- NAIRAS comparisons with existing TEPC/Liulin measurements shows much larger discrepancies in silicon absorbed dose
  - Suggests larger uncertainty in NAIRAS charged-particle source/transport/interactions
  - TOA measurements characterize charged-particle source (i.e., cosmic ray primaries)

<table>
<thead>
<tr>
<th>Elapsed Flight Time (Hr)</th>
<th>Ambient Dose Equivalent Rate (µSv/hr)</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Current NAIRAS model underestimates TEPC flight data by 50%</td>
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<th>Elapsed Flight Time (Hr)</th>
<th>Dose Rate (µGy/hr)</th>
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<tr>
<td></td>
<td>Current NAIRAS model underestimates Liulin charged particle flight data by 70%</td>
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[Graphs and data tables showing comparisons between TEPC and NAIRAS models]
### Science Goals and Objectives

- Improve tools that predict energy deposition characteristics of penetrating cosmic radiation in Earth’s atmosphere
  - Measure radiation dosimetry in upper atmosphere
  - Separate cosmic ray primary contributions
- Identify and characterize low-cost radiation measurement solutions
  - Characterize relationship between solid state radiation instruments and biological response

### Mission and Instrument Parameters

- **Platform:** High-Altitude Balloon
- **Launch Site:** Fort Sumner, NM (34N, 104W)
- **Mission Duration:** 20+ hours of science data
- **Temporal Sampling:** 1-5 minutes
- **Launch Date:** September 25-26, 2015
- **Instruments:**
  1. TEPC
  2. TID detector
  3. LET spectrometer
  4. Microdosimeter emulator
- All instrument components at TRL 6 or higher

### Science Team and Partners

- NASA Langley
- NASA ARC
- NASA GSFC/WFF
- Prairie View A & M University (PVAMU)
- Center for Radiation Engineering and Science for Space Exploration (CRESSE)
- Oklahoma State University
- University of Virginia
- Space Environment Technologies, Inc.
High-altitude balloon flight (> 20 km) out of Fort Sumner, NM with dosimeter measurements utilized to improve cosmic radiation dose assessment and characterize the energy deposition from CR primaries

- **N AIRAS** underestimates effective body dose by 50% at lower latitudes (≤ 50°), the region of largest model error [Mertens et al., Space Weather, 2013]. Uncertainty must be ≤ 30% for latitudes ≥ 30° for reliable dose assessments [ICRU Report 84, 2010]

- Measurements > 20 km next step needed to understand source of uncertainty and guide model improvement

**GOALS**

1. **Improve tools that predict**
   energy deposition characteristics of
   penetrating CR in Earth’s atmosphere
   
   - Combine different dosimeter measurements
     and two flight altitudes to assess model uncertainty
     in CR primaries

2. **Identify and characterize**
   low-cost radiation measurement solutions
   
   - Continuous, global measurements for real-time data assimilative modeling
RaD-X Flight Profile

RaD-X Flight Profile

RaD-X FLIGHT PROFILE

~10 Hours

~2 Hrs

~10 Hours

Region B
< 8 hPa
(> 32.5 km)

Line of sight
Balloon Command &
Telemetry

Command &
Telemetry
links through
Iridium Satellite

Region A
18 - 48 hPa
(20.8 - 27.2 km)

Balloon Launch

Termination

45 Min. Descent

CSDF Flight Operations Center

RaD-X Mission Operations Center

RaD-X Science Operations Center
TEPC: Tissue Equivalent Proportional Counter
Far West Technology, Inc.

Liulin LET Spectrometer
Prof. Dachev SRTI-BAS

Total Ionizing Dose (TID) Detector
Teledyne Microelectronic Technologies

RaySure Detector
QinetiQ & Univ. of Surrey, UK
Preparing for Launch at Fort Sumner

Dr. Grunsfeld, NASA SMD Associate Administrator
Dr. Hertz, NASA SMD Astrophysics Division Director
RaD-X PI at Fort Sumner

Waiting for Launch at Fort Sumner
RaD-X Payload Ready for Launch

Payload integrated to balloon gondola

“Big Bill” transporting payload to launch site
RaD-X Launches Sep 25, 2015
RaD-X Absorbed Dose Rate

Absorbed Dose Rate Measured by TEPC and Liulin

RaD-X Balloon Flight All Instrument Data (No TID) - 09/25/15 to 09/26/15 - Dose Rate

Dose Rate (µGy/hr)

Date & Time (UT)

Region B (< 32.5km)
Avg. Altitude: 36.7km
Avg. Pressure: 4.52 hPa
Duration: 6:33:32

Region A (21.0km - 27.0km)
Avg. Altitude: 24.3km
Avg. Pressure: 27.28 hPa
Duration: 8:23:22

November 17, 2015
Bulgarian Academy of Sciences
TEPC Measurements of Dose Equivalent and Ambient Dose Equivalent Rates

Ra-D-X Balloon Flight All Instrument Data - 09/25/15 to 09/26/15 - Ambient Dose Equivalent & Dose Equivalent Rate

- Ambient Dose Equivalent Rate TEPC | Averages - Region B: 11.13 µSv/hr Region A: 9.08 µSv/hr
- Dose Equivalent Rate TEPC | Averages - Region B: 9.44 µSv/hr Region A: 7.72 µSv/hr

Region B (> 32.5km)
Avg. Altitude: 34.27 km
Avg. Pressure: 6.44 hPa
Duration: 6:33:52

Region A (21.0km - 27.0km)
Avg. Altitude: 23.78 km
Avg. Pressure: 31.27 hPa
Duration: 8:23:22

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• TEPC Dose Rate Profiles
  – Constructed from +/- 10 minute widow average of measured dose rates
  – Absorbed Dose Rate (Dose) Profile (Top Right)
  – Dose Equivalent (DoseE) Rate (Bottom Right)

• Dose Profile Features
  – Very broad Pfotzer maximum corresponding to the peak in the dose rate

• DoseE Profile Features
  – Key Finding: No Pfotzer maximum in DoseE
  – Lack of low-LET secondary particles above ionization peak is compensated by high-LET albedo neutrons and cosmic ray primary particles
  – Increase in DoseE in Region B due to HZE particles
RaD-X/NAIRAS comparisons preliminary until barometric pressure differences resolved
• **RaD-X TEPC /NAIRAS Comparisons**
  
  – Dose Equivalent Rate (DoseE):
    
    o DoseE includes radiobiological weighting of neutrons and other high-LET particles
    
    o NAIRAS underestimate by less than 10%
  
  – Absorbed Dose Rate (Dose):
    
    o Dose insensitive to neutrons
    
    o NAIRAS underestimate by > 50%

• **Trend in NAIRAS Comparisons to the Other Measurements** (RaD-X Liulin, ER-2 TEPC, King Air C90 TEPC/Liulin)
  
  – NAIRAS underestimate measurement data
  
  – Differences largest near Pfotzer maximum (peak in absorbed dose rate)

• **Preliminary Inferences**
  
  – NAIRAS underestimates pion-initiated electromagnetic (π-EM) cascade processes
    
    o Underestimate charged particle (low-LET) contributions to Dose/DoseE
    
    o Overestimate neutron (high-LET) contributions to DoseE
  
  – π-EM backscatter appears to be important (Region A in particular)
  
  – NAIRAS may underestimate cosmic ray primary protons
• The TEPC Dose-LET spectra show the different particle content in Regions A and B
  – Compare relative contributions from High-LET events
  – High-LET event > 10 keV/um
• Region B: evidence of HZE particles
  – Larger contributions from high-LET events in Region B
• Region A: Cosmic ray primary protons and albedo neutrons
  – High-LET events but much smaller contributions to dose in Region A compared to Region B
• Peak in Region B Dose-LET spectrum interesting and needs further investigation
• RaD-X ConOps design of the two float altitudes (Regions A and B) succeeded in isolating HZE cosmic ray primary particle contributions to dose
## Average Dose: RaD-X + Aircraft

<table>
<thead>
<tr>
<th>Altitude km</th>
<th>Pressure hPa</th>
<th>Platform</th>
<th>Liulin Dose Rate uGy/hr</th>
<th>TEPC Dose Rate uGy/hr</th>
<th>TEPC Dose Equiv uSy/hr</th>
<th>TEPC H*(10) uSy/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>444.9</td>
<td>King Air C90</td>
<td>0.94 ± 0.02</td>
<td>0.90 ± 0.01</td>
<td>2.44 ± 0.11</td>
<td>N/A</td>
</tr>
<tr>
<td>17</td>
<td>92.0</td>
<td>ER-2</td>
<td>N/A</td>
<td>4.63 ± 0.02</td>
<td>8.95 ± 0.22</td>
<td>N/A</td>
</tr>
<tr>
<td>20</td>
<td>85.6</td>
<td>ER-2</td>
<td>N/A</td>
<td>5.00 ± 0.03</td>
<td>10.26 ± 0.34</td>
<td>N/A</td>
</tr>
<tr>
<td>24.3</td>
<td>27.3</td>
<td>RaD-X</td>
<td>3.34 ± 0.03</td>
<td>3.20 ± 0.01</td>
<td>7.70 ± 0.13</td>
<td>9.05 ± 0.15</td>
</tr>
<tr>
<td>36.7</td>
<td>4.5</td>
<td>RaD-X</td>
<td>2.77 ± 0.04</td>
<td>2.73 ± 0.01</td>
<td>9.40 ± 0.17</td>
<td>11.09 ± 0.20</td>
</tr>
</tbody>
</table>
• All instrument flight data recovered and suitable for scientific investigation
• TEPC absorbed dose rate profile shows very broad Pfotzer maximum,
• TEPC dose equivalent profile shows no Pfotzer maximum at all
  – Indicative of high-LET albedo neutrons and cosmic ray primaries
• Assessment of NAIRAS
  – Qualitatively captures the essential features of the atmospheric ionizing radiation field
    o Adequately defined the science objectives and Flight ConOps to achieve science goals
  – Quantitatively, its underestimation of the measurements point to the following deficiencies
    o Inadequate production of $\pi$-EM particles (i.e., the complex region), highlighting the role of backscatter contributions
    o Possibly underestimation of cosmic ray primary protons