Low-Power Multi-Aspect Space Radiation Detector System

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Abstract
The advanced space radiation detector development team at NASA Glenn Research Center (GRC) has the goal of developing unique, more compact radiation detectors that provide improved real-time data on space radiation. The team has performed studies of different detector designs using a variety of combinations of solid-state detectors, which allow higher sensitivity to radiation in a smaller package and operate at lower voltage than traditional detectors [1-3]. Integration of all of these detector technologies will result in an improved detector system in comparison to existing state-of-the-art (SOA) instruments for the detection and monitoring of the deep space radiation field.

Challenges & Solutions
- Mapping of heavy ions > 200 MeV/amu
  Solution: Integrated solid-state Cherenkov detector system with large area detectors
- High radiation flux rates for 10+ year missions
  Solution: Precision rad-hard, thermally stable wide band gap detectors
- Low noise, multi-directional measurements at single locations
  Solution: Compact, spherical detector system

Approach:
- Develop new robust, low power, thermally stable solid-state technologies as radiation detectors to improve lifetime, power and noise performance
- Demonstrate omni-directional measurements of radiation using novel integrating techniques
- Integrate multiple types of detectors and materials to expand energy range and sensitivity for lower mass, power and volume requirements

Research Objectives
Develop detector technologies to enable a low-power radiation detector system capable of monitoring a wide range of high energy heavy ions (HZE ions) over a spherical (4π) aspect area [8,9]

References:
Low-Power Multi-Aspect Space Radiation Detector System. J. D. Wrbanek, G. C. Fralick, C. Freeman and S. P. Berkebile. NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH; Oak Ridge Associated Universities, NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135, Email address: John.D.Wrbanek@nasa.gov

Introduction: The advanced space radiation detector development team at NASA Glenn Research Center (GRC) has the goal of developing unique, more compact radiation detectors that provide improved real-time data on space radiation. The team has performed studies of different detector designs using a variety of combinations of solid-state detectors, which allow higher sensitivity to radiation in a smaller package and operate at lower voltage than traditional detectors [1-3]. Integration of all of these detector technologies will result in an improved detector system in comparison to existing state-of-the-art (SOA) instruments for the detection and monitoring of the deep space radiation field.

The goal of this research is to develop a low-power radiation detector system capable of monitoring a wide range of high energy heavy ions (HZE ions) over a spherical (4π) aspect area [4, 5]. The technology applied to this 4π HZE Detector System enables:

- Improved temperature insensitivity to changes induced by transitions from sunlight into shadow (and vice-versa);
- Improved precision with lower mass, power and volume requirements;
- Improved radiation discrimination and directional sensitivity;
- Unique monitoring of radiation environment of high relevancy for planetary exploration from all directions of the celestial sphere.

New Capabilities: New capabilities for radiation measurement in exploration beyond Earth orbit are realized from a variety of low-power detectors. Due to limited resources available for power and space for payloads, miniaturizing and integrating instrumentation is a key aspect to enabling manned and unmanned deep space missions to High Earth Orbit (HEO), Near Earth Objects (NEO), Lunar and Martian orbits and surfaces, and outer planetary systems. New, robust compact detectors allow future instrumentation packages more options in satisfying specific mission goals. Technology limiters are primarily detector size, noise floor and detection geometry. Enabling technology solutions for these limitations are development of low noise, integrated solid state detectors with spherical geometry.

Integrating the variety of detectors will allow measurements of radiation of different types from different directions at once, something that is not available with current state-of-the-art detectors. Space radiation comes in a variety of types, energies, and directions. Current SOA detector technology is large, power consuming, and thus reducing the size and operational power will improve mission affordability. The variety of radiation in space demands a suite of detectors tailored to accurately monitor and analyze the various types. NASA GRC is developing a variety of light weight, low-power solid state detectors that can increase the variety and energies of radiation able to be detected and yet reduce the amount of space and power consumed by current SOA. This will enable more accurate and unique measurements of high relevancy for the radiation environment in missions beyond Earth orbit.

System Development Approach: Advanced instrumentation technology for space radiation applications is specifically called for in the Strategic Program Plan for Space Radiation Health Research [6]. The NASA Space Technology Roadmaps and Priorities [7], the Science Instruments and Sensor Capabilities Road Map [8], and the design goals of existing cosmic ray detectors define the technology requirements [9]. These requirements include particle energy range and resolution, angular coverage and resolution, and the number of sensing elements as important design criteria in trade studies.

A variety of detector types, including low noise, wide band gap (WBG) semiconductors are considered applicable for radiation detectors due to their low ionization energy, high electron mobility, high density and structural rigidity. A concept schematic drawing of a spherical detector system comprising a spherical Cherenkov detector, surrounded by various arrays of detector stacks is shown in Figure 1. Most of the technology in this detector system has been demonstrated at some level, but the challenge is to design and develop unique detection array methods in coordination with advancing these technologies. Some of the specific goals of these instrumentation efforts are:

- Apply scintillator ribbon material where appropriate to detect radiation impinging over large, irregular surfaces where electronic device placement is not feasible. The flexibility of an advanced fiber-based detector system is an attractive option to allow embedded multidirectional radiation characterization and precision trigger/veto functionality.
• Demonstrate a spherical Cherenkov detector that can detect radiation from all directions, amplifying signal through use of integrating sphere properties designed into detector. Current detectors have directional sensitivity along one axis, and this spherical detector increases the directional sensitivity to any direction. Immersed in the space environment, where radiation is omni-directional, measurements sensitive over an entire sphere is a significant improvement from interpolating along discrete axes.

• Develop a variety of stacked detectors with various solid state detectors, absorbers and converters for optimum detection of electrons, neutrons and ions in a small, low-power package. A miniature detector stack will reduce mass, power, and volume requirements as well as improving particle species discrimination and spatial resolution.

• Apply WBG solid state devices as practical large area detectors. WBG semiconductors have the advantages of low ionization energy, high electron mobility, high density and structural rigidity as for use as radiation detectors. WBG semiconductors have negligible sensitivity to temperature changes as well, a direct benefit for space applications.

The realization of the detector system leverages in-house GRC expertise and facilities in 1) harsh environment thin films, 2) silicon carbide (SiC) devices and harsh environment packaging, 3) micro-optics technology, and 4) structural radiation shielding materials. Integration of all of these technologies will result in an improved detector system in comparison to existing state-of-the-art capabilities as summarized in Table 1. As mission needs change, the detector technology integration can be adapted for performance and optimal science benefit.


Table 1: Potential improvements to critical metrics for advanced space radiation detection.

<table>
<thead>
<tr>
<th>CRM Metric</th>
<th>CRM Enabler</th>
<th>Improvement Enabler</th>
<th>Detector System Expected Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>140 MeV/mu</td>
<td>Integrated Detectors</td>
<td>1,000 MeV/mu</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>≤50 eV</td>
<td>Low Noise Detectors</td>
<td>≤20 eV</td>
</tr>
<tr>
<td>Angle Coverage</td>
<td>0.5 mrad</td>
<td>Spherical Geometry</td>
<td>1 mrad</td>
</tr>
<tr>
<td>Angle Resolution</td>
<td>≤1°</td>
<td>Solid State Detectors</td>
<td>Solid State Detectors</td>
</tr>
<tr>
<td>Particle Species</td>
<td>Multiplier in multiple detectors</td>
<td>Integrated Detectors</td>
<td>Integrated Solid State Detectors</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>Defined by Detectors</td>
<td>Integrated Detectors</td>
<td>30% SOA</td>
</tr>
</tbody>
</table>

Figure 1: Concept of an Integrated Spherical Space Radiation Detector System [5].