EVALUATING SPACE WEATHER ARCHITECTURE OPTIONS TO SUPPORT HUMAN DEEP SPACE EXPLORATION OF THE MOON AND MARS, L. Parker[1], J. Minow[2], A. Pulkkinen[3], D. Fry[4], E. Semones[4], J. Allen[5], C. St Cyr[3], C. Mertens[6], I. Jun[7], T. Onsager[8], and R. Hock[9]. [1]Universities Space Research Association, [2]NASA Marshall Space Fligh Center, [3]NASA Goddard Space Flight Center, [4]NASA Johnson Space Flight Center, [5]NASA HQ, [6]NASA Langley Research Center, [7]NASA Jet Propulsion Laboratory, [8]NOAA Space Weather Prediction Center, [9]Air Force Research Laboratory.

Introduction: NASA's Engineering and Space Center (NESC) is conducting an independent technical assessment of space environment monitoring and forecasting architecture options to support human and robotic deep space exploration with William H. Gerstenmaier, Associate Administrator for the Human Exploration and Operations Directorate (HEOMD) serving as the primary stakeholder for the study. The assessment that is being currently conducted considers near-real-time monitoring and forecast needs for space radiation.

The assessment will provide NASA with options for a robust and cost-effective space weather situational awareness architecture that can effectively reduce space radiation risks for crewed and robotic operations in the inner heliosphere in orbits about Earth, cislunar space, and Mars.

Scope: Human and robotic deep space exploration activities at low Earth orbit are relatively well protected from the charged particle radiation caused by galactic cosmic rays and eruptive solar events. However, as the Agency moves forward with its lunar Deep Space Gateway and ultimately journey to Mars goals, many key future human space exploration activities will take place outside the Earth's protective magnetic shielding. Space weather hazards, e.g., charged particle radiation, are some of the key challenges to be addressed when humans enter the deep space environment.

As recognized in the report, "NASA's Efforts to Manage Health and Human Performance Risks for Space Exploration" [1], space radiation remains a top risk for human and robotic deep space exploration. Limited knowledge about degenerative radiation effects is a key concern. While much remains to be understood, it is clear that any reasonable risk mitigation will require advanced situational awareness about space environment conditions that lead to radiation exposure. It is likely that as a part of the risk mitigation, some form of crew storm-shelter procedures will be implemented and executed based on real-time and possibly predictive information about the space environment.

The establishment of robust space weather situational awareness will demand joint usage of observations, models, and analysis. Given the complex nature of the heliosphere, a variety of approaches will be required for an optimal outcome. Further, while leveraging existing interagency and international space weather capabilities, uniquely human and robotic deep space exploration needs and procedures must be considered.

Technical Activities: The assessment will consider near-real timemonitoring assets, space radiation analysis tools, and forecast methods that can support human-vehicle systems for HEOMD and robotic systems for Science Mission Directorate (SMD) missions beyond low Earth orbit in the areas of:

- *In-situ* radiation monitoring hardware planned for deployment on exploration vehicles;
- Existing space environment sensors from NASA, National Oceanic and Atmsopheric Administration (NOAA), the Department of Defense (DoD), and other organizations to the greatest extent possible; and
- A minimal set of new hardware only where necessary.

The technical activities for the assessment include six tasks:

Task 1: Review of Previous Material

Review of prior/current work on space weather architectures to understand any possible gaps in knowledge in fulfilling the requirements. Specifically, the assessment team will consider hardware requirements, habitat designs including storm shelters for manned missions, and space weather monitoring assets for future missions using information from NASA, NOAA, and DoD, such as:

- Availability of space weather monitoring assets for future missionsNational Space Weather Action Plan (SWAP) and Space Weather Operations, Research, and Mitigation (SWORM) activitiesHuman Systems Integration Requirements (HSIR, CxP 70044) and Design Specification for Natural Environments (DSNE, CxP 70023) documents.

Task 2: Assessment of Operational Response Time for Space Weather Monitoring

Develope possible operational response sequences for given sets of observations, models, and tools. This would include assessing the data-stream parameters required for decision making.

Task 3: Review of Relevant Forecasting Tools

Develope a catalogue of physics-based and empirical models and tools for use in conjunction with different observational architectures.

Task 4: Assessment of Solar Energetic Particle (SEP) Threshold Levels for Exploration Missions

- Revisit the current SEP constraints to assess if they are appropriate for Orion, Mars Habitat, and extravehicular activity (EVA).
- Provide recommendations for appropriate SEP constraints.

Task 5: Development of Space Weather Architectures

- Using the latest human deep space exploration scenarios (e.g., cislunar space, Mars, Moon) together with information about possible storm-shelter options, develop two to three observational architectures in support of operational response to major solar events. Architectures include observation locations and instrument types. Importantly, synergies between science and operational monitoring will be considered.
- Assess current and future satellite assets for any gaps in observations (e.g., SOHO, STEREO replacement, possible European Space Agency (ESA) L5 mission, Deep Space Climate Observatory (DSCOVR) follow-on).
- Provide a cost/benefit analysis of additional satellite assets.

Task 6: Space Weather Architecture Cost Estimates

Develope first-order cost estimates for the space weather architectures developed in Task 5. Emphasis will be placed on the most cost-effective solutions that leverage existing national operational space weather infrastructure.

Conclusions:

The NESC assessment team is developing and delivering the assessment report that is due by the end of FY18. The report will cover:

- Two to three space environment/weather monitoring and forecasting architecture options for safeguarding human and robotic deep space exploration. Existing interagency and international space weather capabilities will serve as the baseline for human space exploration-specific considerations.
- High-level specifications for the missions, instruments, systems, and activities associated with the options.
- Estimated costs of the options.

References:

[1] NASA Office of Inspector General, NASA'S Efforts To Manage Health And Human Performance Risks For Space Exploration, *OIG Report No. IG-16-003*, October 29, 2016.