An Overview of

THE SPACE RADIATION ANALYSIS GROUP AT NASA/JSC

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Outline

- Introduction to SRAG
- Sources of Space Radiation
- Radiation Instrumentation on the ISS
- Next Generation Radiation Instrumentation for exo-LEO Missions
- SRAG Needs in Terms of Mission Planning and Response

Operations: Who Are We?

Space Radiation Analysis Group (SRAG)

Diverse group of research scientists and engineers, specializing in physics, biology, epidemiology, and statistics.

4 civil servants

21 contractors

- Provide radiation monitoring to meet medical and legal requirements
- Provide real-time astronaut radiation protection support
- Maintain comprehensive crew exposure modeling capability
- Provide operational dosimetry

Space Radiation Health Risks

Health Risk Areas	Status
Carcinogenesis Space radiation exposure may cause increased cancer morbidity or mortality risk in astronauts	➢ Cancer risk model developed for mission risk assessment ➢ Model is being refined through research at NASA Space Radiation Laboratory (NSRL) ➢ Health standard established
Acute Radiation Syndromes from SPEs Acute (in-flight) radiation syndromes, which may be clinically severe, may occur due to occupational radiation exposure	➢ Acute radiation health model has been developed and is mature ➢ Health standards established ➢ Operational & shielding mitigations are understood & risk area is controlled
Degenerative Tissue Effects Radiation exposure may result in effects to cardiovascular system, as well as cataracts **Central Nervous System Risks (CNS)** Acute and late radiation damage to the central CNS may lead to changes in cognition or neurological disorders	➢ Non-cancer risks (**Cardiovascular and CNS**) are currently being defined ➢ Research is underway at NSRL and on ISS to address these areas ➢ May need appropriate animal models to assess clinical significance

ALARA

- **As Low as Reasonably Achievable (ALARA)**
  - A commitment to make all reasonable efforts to minimize exposure, and hence to reduce risk.
  - Part of the Legal limits. Just as important as the 'Numerical limits'
  - Why?
    - Any exposure, no matter how small, results in a finite (albeit small) increase in subsequent cancer risk (no threshold theory)
  - "means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest" (NRC 10CFR Part 20 §20.1003)

SRAG Modeling and Analysis

The Space Radiation Analysis Group (SRAG) maintains a comprehensive set of codes and models for evaluation of radiation exposures.

- **Environmental Models**
  - Provide characterization of conditions encountered in space
- **3 Dimensional Spacecraft CAD Models**
  - High fidelity models of spacecraft mass distribution for shielding analysis
- **Radiation Transport Models**
  - Allow accurate characterization of the changes in radiation fields within matter (vehicles, habitats, human body, etc.)
- **Integrated Analysis Tools**
  - combined vehicle, environmental, and transport models for assessments of radiation environment within spacecraft
- **Crew Risk Estimation**
  - Assessment of biological impact of radiation and potential for negative health effects

Visualization of vehicle model components used in analysis of radiation shielding effectiveness

SRAG Preflight Planning Support

Prepare and ship operational dosimetry hardware

Pre-flight space radiation mission assessment

- Report radiation environment evaluations to flight management at Flight Readiness Reviews
    - IVA - exposures
    - EVA – exposure vs. timing (planned and contingency)
    - Space environment monitoring – past and projected trends
    - Ensure radiation exposures are within prescribed limits and as low as reasonably achievable (ALARA)
    - Evaluate radiation generating equipment and radioactive material exposure assessment
- Brief crew on projected exposures, recent space weather activity and forecasts, reduction of EVA exposures, "storm shelter" locations, and radiation instrument status during Pre-Flight Medical Refresher

Radiation Dosimetry Lab
JSC B15

SRAG Real-Time Flight Support

Support operations in Mission Control Center-Houston 4 hr/day during nominal conditions (Radiation Console)

- Monitor space weather conditions
- Check vehicle status and crew timeline for potential unscheduled EVAs
- Report crew exposure status and space weather conditions to flight management

SRAG MPSR

24/7 console support in MCC-H during significant space weather activity

- Automatically receive NOAA SWPC alerts when events exceed set criteria
- Receive messages from SRAG Space Weather Monitoring and Alarm System
- Continuous support until event conditions clear

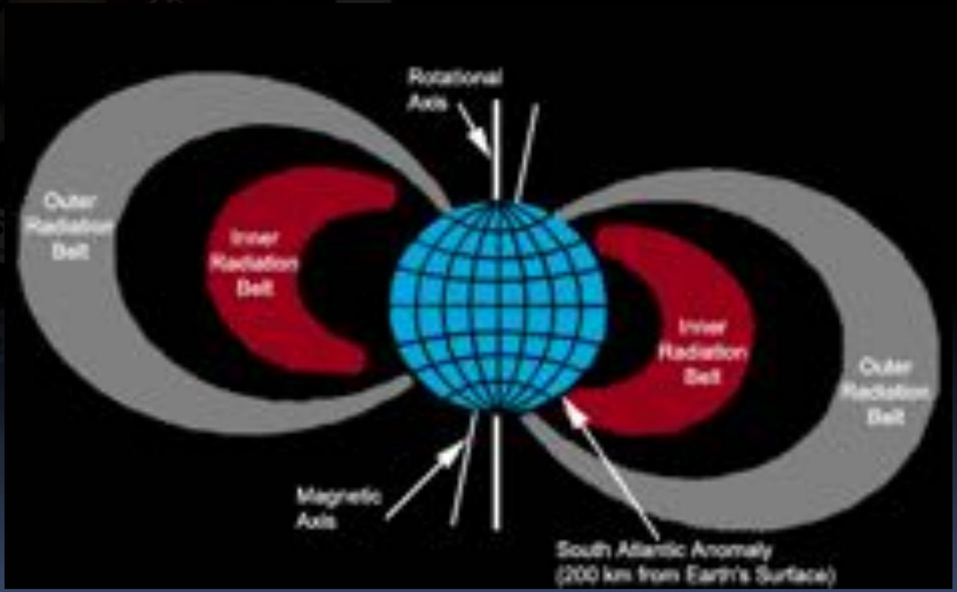
Sources of Exposure

GCR – Galactic Cosmic Radiation

- High Energy – Very Penetrating – Hard to Shield
- Biologically Most Damaging
- Highest in open magnetic field areas (aka low cutoff zones)

Trapped Radiation – South Atlantic Anomaly

- Protons trapped by the magnetic field
- Specific location defined by Geomagnetic field offset and tilt
- Altitude dependent



Trapped Electrons

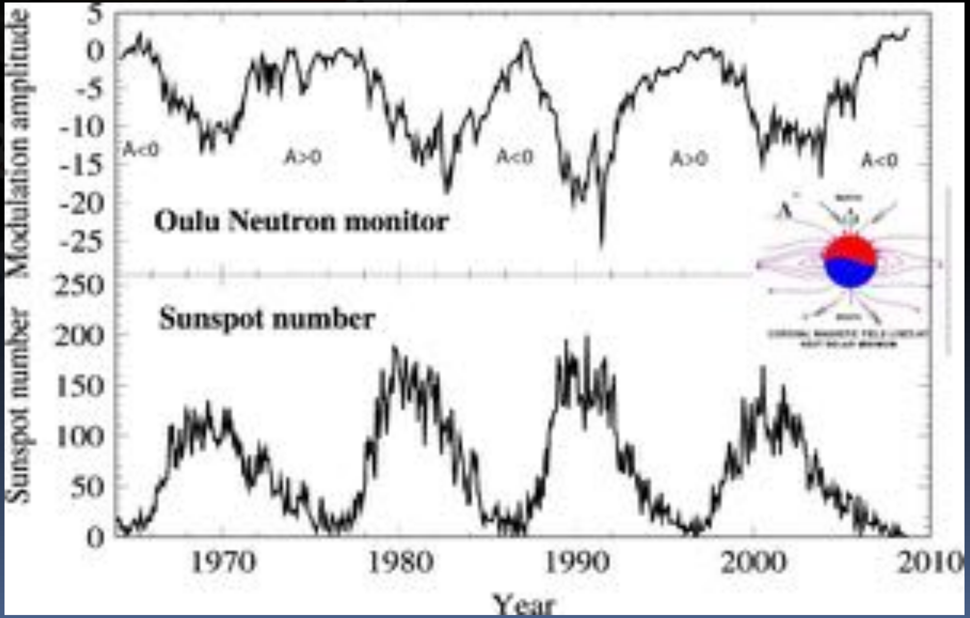
- EVA hazard
- Highest near low cutoff zones
- Magnetic storms can cause 50-fold increase in level and redistribute electrons into different locations

Solar Proton Events

- Mostly protons from localized energy releases from the sun
- Exposure risk is from transits through low cutoff zones

Galactic Cosmic Ray (GCR) Background

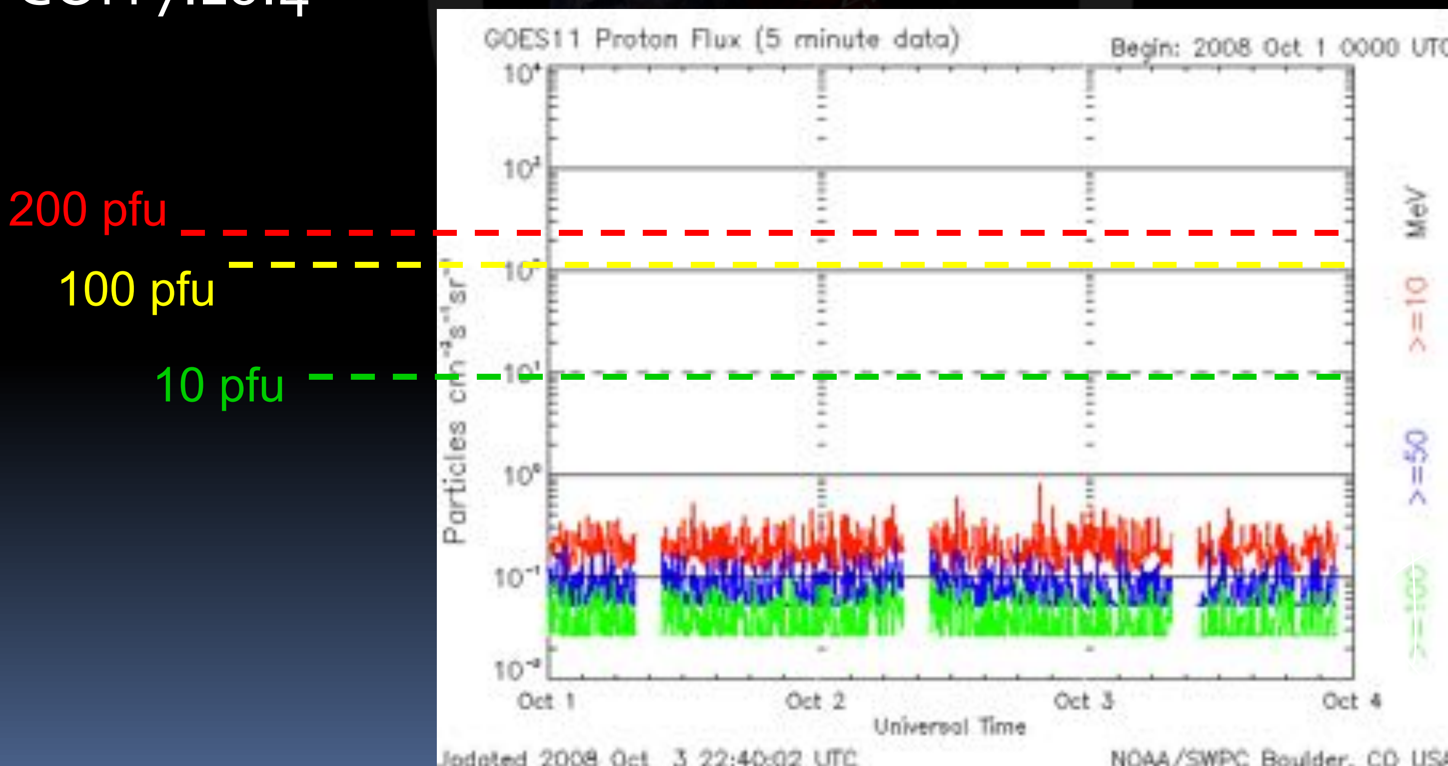
- The highly energetic GCR background forms a continuous radiation source for astronauts in space
- GCRs are modulated by the Sun
  - Anti-correlated with the solar activity cycle
  - High levels of GCR during solar minimum
  - Low levels of GCR during solar maximum
- Important to mitigate the radiation exposure due to GCRs during long-duration space missions
- Need to predict the solar cycle into the future for mission planning and dose estimates



Heber et al. (2009) http://stacks.iop.org/0004-637X/699/i=2/a=1956

Radiation Events

- Provide updates to Surgeon and Flight Team as events progress
- FD contacted directly for severe, time-critical events per ISS FCOH 7.10.4



Energetic Solar Particle Events (ESPE's)

Can deliver high flux levels of protons

Arrival times between minutes to hours.
Typical average ~ 30 minutes

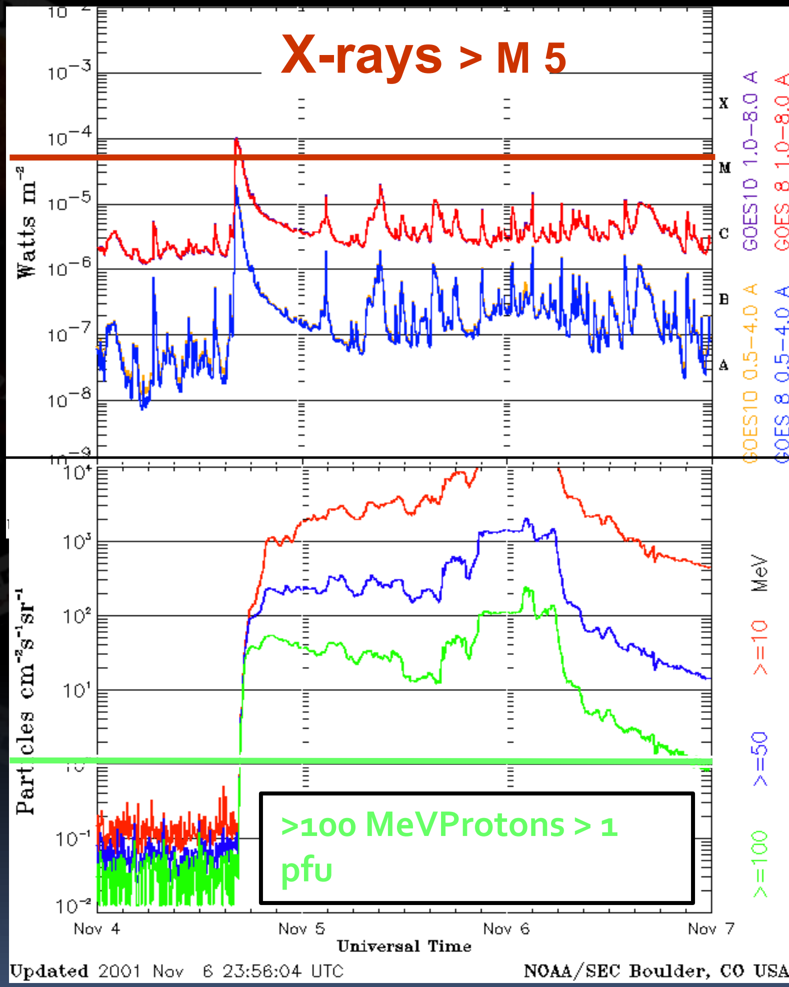
High proton energies up to 1000 MeV

>100 MeV to get inside spacecraft

>10 MeV to get inside EVA suit

Trajectory and timing will influence the total exposures

Green proton value exceeds the green line: Continuous MCC Support



Horizontal lines (red & green) are alarm/action levels

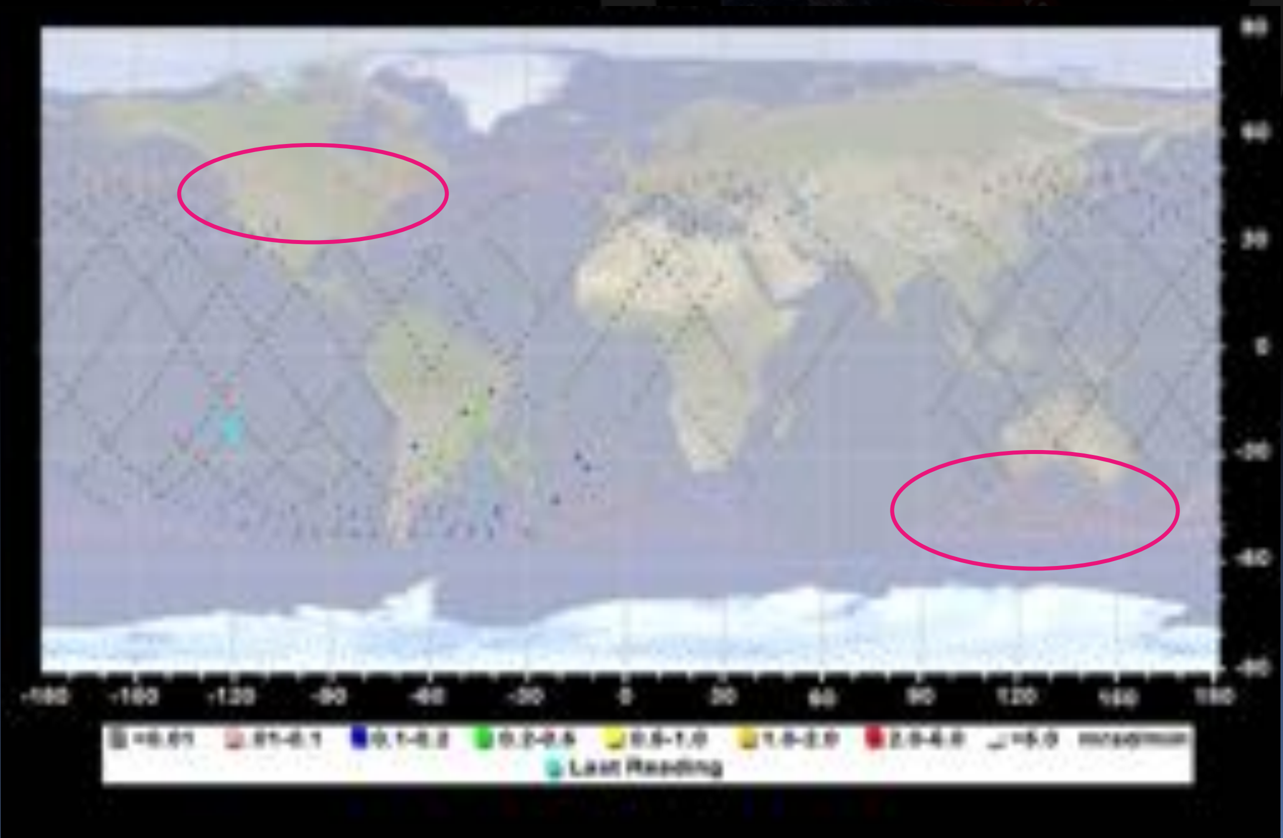
SPE Event - Characteristics

SPE Event

- Characterized by short high-dose passes
- Peaks will be 45 – 90 minutes apart
- Passes correspond to trajectories in low geomagnetic cut-off areas

Ground Support

If the event is large – timetable of passes will be provided to crew, SRAG will track on ground.



Orbital phasing relative to high dose rate passes is important

ISS Radiation Instrumentation

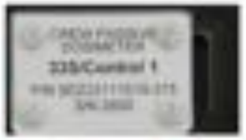
- CPDS – Charged Particle Directional Spectrometer (2001)
  - Extra-Vehicular instrument
  - Stack of Silicon and Cerenkov detectors

- TEPC – Tissue Equivalent Proportional Counter (2007)
  - Permanently deployed in Service Module
  - Cylindrical gas filled detector to simulate 2µm diameter tissue

- IV-TEPC – new TEPC detector (2012)
  - Permanently deployed in Node 2. Used to relocated every 4-6 weeks.

- Passive Radiation Dosimeters for Personal and Area Monitoring
  - Crew Passive Dosimeters (CPD) – crew worn
  - Radiation Area Monitors (RAM) – deployed at different ISS locations
  - OSL/TL dosimeters: Luxel (Al_2O_3:C); TLD-100 (LiF:Mg,Ti); TLD-300 (CaF_2:Tm); TLD-600 (^{6}LiF:Mg,Ti); TLD-700 (^{7}LiF:Mg,Ti)

CPD



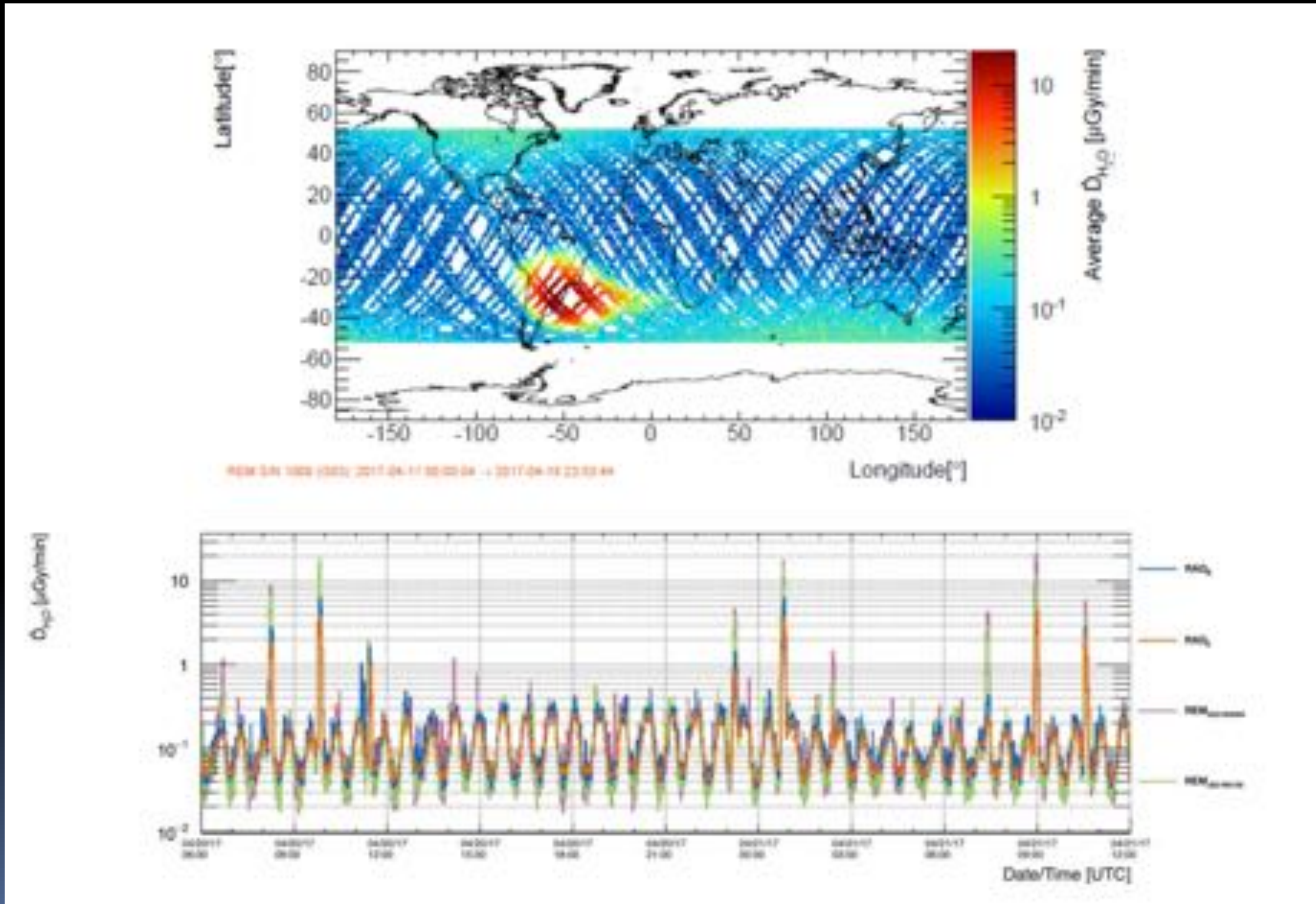
RAM

ISS Radiation Instrumentation

- REM – Radiation Environment Monitor (2012)
  - Active dosimeter with USB interface
  - Based on Hybrid Pixel Detector technology
  - ISS Technology Demonstration
- RAD – Radiation Assessment Detector (2016)
  - Based on the Mars Science Laboratory (MSL) RAD instrument
  - Successfully completed ISS Activation & Checkout; Survey ISS
  - Charged particles spectrometer (CPD) and neutron detector (FND)
- MPT – Miniaturized Particle Telescope (2017)
  - ISS TechDemo to demonstrate the capability of determining the directional characteristics of charged particle energy spectra in space
  - Deployed at different locations inside ISS

REM

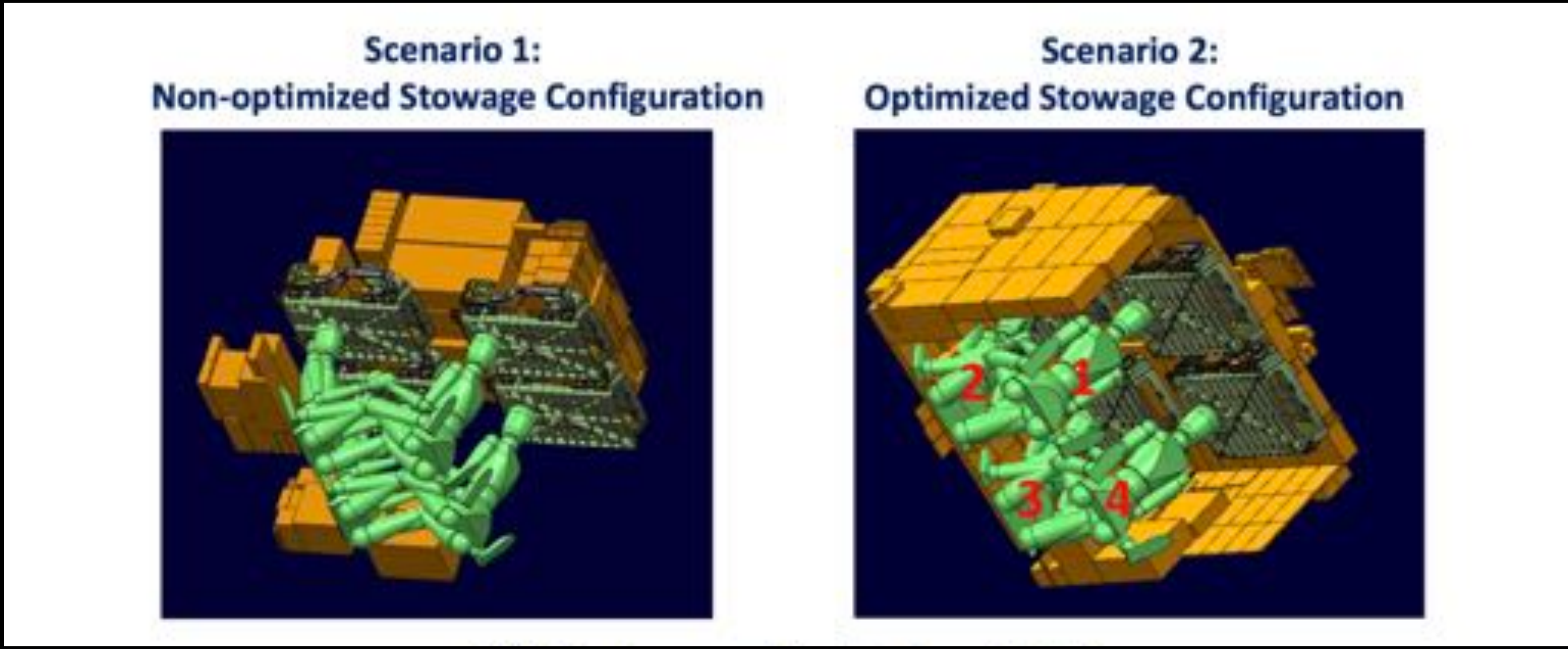
ISS Radiation Instrumentation



Exo-LEO Missions

- Radiation devices are being developed and tested to monitor crew conditions during exo-LEO missions
  - Crew Personal Active Dosimeters (CPAD)
  - Hybrid Electronic Radiation Assessor (HERA)
- Will fly on future Orion missions
- Onboard analysis and vehicle displays (dose rate, mission dose) from detectors placed in various locations throughout the spacecraft
- Alarm capability, first radiation detector to be integrated with the onboard Caution and Warning System (dose rate threshold)

SPE Contingency Plan



Models show that optimizing the stowage configuration during SPEs reduces radiation exposure

Missions beyond LEO where crew-vehicle system spends substantial time in 'free- space' the scenario is very different:
Human-vehicle will see full extent of storm!

SRAG Perspective

- Mission planning, vehicle, and shelter design driven by extreme cases – deep solar minimum and extreme SPEs
- Projected mission doses due to GCR depend on ability to predict solar cycle into the future
- At onset of SPE, need to be able to predict peak and total event dose to decide upon contingency solutions
- From a space weather perspective, need ability to quantify risk that an SPE will occur and its spectral intensity and subsequent dose as a function of mission duration for exo-LEO missions
- Need to transition from space weather now-casting to forecasting

Summary

- SRAG uses models, instrumentation, and space weather information to monitor and predict the radiation environment, alert and provide support operations during high radiation events, and assess the biological risk to astronauts
- Radiation monitoring is ongoing on the ISS and the spacecraft radiation environment will be monitored with alarm capabilities on future exo-LEO missions
- Need space climate and space weather forecasting as well as All-Clear capabilities for exo-LEO Missions