Radiation Risk Management on Human Missions to the Moon and Mars

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Space radiation poses a significant risk to astronauts embarking on exploration missions to the Moon and Mars. Meeting the challenge will involve the space physics research community as well as the mission planning and operations communities. This talk gives an overview of the radiation risk and discusses a systems architecture approach to reduce the risk. A key conclusion is that work must begin now to lay the groundwork necessary to ensure the appropriate space weather network is in place before humans return to the Moon by 2018.
The Myths, the Grail, the Reality

Solar Particle Events are killers

All you need is modest shielding

We’ll never be able to forecast SPEs

We must have a far side solar observatory
The Myths, the Grail, the Reality

• Science-based understanding and appropriate observations enabling operationally robust models forecasting the space environment in a timely fashion...
• ...Contributing to an overall risk mitigation architecture that includes
  • Adequate shelter,
  • Effective radiation monitoring,
  • Reliable communications, and
  • Integrated mission planning and operations concepts
• ...To ensure the safety of astronauts throughout the various phases of missions planned for the space exploration vision
The Myths, the Grail, the Reality

• Each component of a risk management strategy must contribute to enhanced safety of the astronauts on exploration missions
• There is only one more solar cycle before humans return to the Moon
• The transition from research to operations is not easy
• Funding will always be limited

It is not clear who is in charge of the overall effort
Communities?

- Vision
- Funding levels
- Planners
- Developers
- Operators
  - Mission Control
  - Astronauts
  - Forecast Centers
- Science
  - Space Physics
  - Space Weather
  - Life Science
How Bad Can an SPE Be?  
Selected Historical Events

Lunar Surface BFO Radiation Dose (cGy)

- 50% Chance of Death
- 10% Chance of Death
- 5% Chance of Death
- 5% Chance of Vomiting

Differential Fluence Spectra  
(particles/MeV-cm²)

CentiGray

FEB 56  NOV 60  AUG 72  AUG 89  SEP 89  OCT 89

Shielding Thickness  
(g/cm² Aluminum)

- 30.0
- 10.0
- 5.0
- 0.3

MeV

10  100  1000
Radiation Risk Mitigation Objective

Top Level Requirement

*NASA has a legal requirement to establish radiation limits*

Any mission must be designed to ensure that radiation exposures do not become comparable to these radiation limits

System Level Requirements

*Reduce the impact of the radiation environment enough to achieve the top level requirement*

*Forecast the radiation environment with adequate timeliness to take appropriate actions*
Potential Elements of an SPE Risk Mitigation Architecture

Detection/Forecast

Active and passive dosimeters, dose rate monitors

*In situ* particle, plasma monitors

Solar imagers, coronagraphs

Remote sensing of plasma properties

Forecast models, algorithms

Data/information communications infrastructure

Reduction

Active and Passive shielding

Storm shelters

Operational procedures, flight rules

Reconfigurable shielding

Particle transport, biological impact models/algorithms

Prescreening for radiation tolerance

Pharmacological measures

Alert/warning communications infrastructure
Forecasting SPE is a Multidiscipline Challenge

- Predict the eruption of a CME
- Predict the character of the CME
- Predict the efficiency of the CME to accelerate particles
- Predict the particle escape from shock and subsequent transport through heliosphere
Step One: Establish Strategic Objectives

Step Two: Identify Mission Architecture

Step Three: Conduct Shielding Analysis

Step Four: Develop Surface Operations Concept

The Most Important Component of Operations is Real-time Event Detection, Communication

Most of the Solution is Sufficient Shielding

Major Role of Space Weather Community: Provide Situation Awareness and Minimize False Alarms
One Approach to Radiation Safety

Consider GCR Radiation Environment

Model Mission Exposure

Increase Habitat Shielding

No

Is Mission Within Limits?

Yes

Consider Worst Case SPE

GCR

Shielding is the Main Defense against Radiation

Model Mission Exposure

Is Mission Within Limits?

No

Yes

SPE

Add/Increase Storm Shelter

EVA?
Surface Operations are Rule-Driven

- Astronaut activities are managed against a set of “Flight Rules”
- These Rules define the overall Concept of Operations (CONOPS)
- CONOPS should reflect the best science available to the mission planners
- Translation of research to operations is not trivial and needs thoughtful scientist input

In-situ Radiation Monitoring is the Main Input to Operations
Radiation Risk Management Investment Strategy
SW Architecture Investment Strategy

- dosimeter
- particle monitor
- plasma monitor
- solar imager
- nowcast/forecast
Only One More Solar Cycle to Learn What We Must Learn

2000

2010

2020

2030

SOHO

ACE

STEREO

Solar B

Solar Dynamics Observatory

Sentinels

Human Mission Design

Return to the Moon

Follow-on Solar Science Missions

On to Mars

Solar Cycle 24

Follow-on Solar Science Missions
We Must Begin Now to Identify the Operational Spacecraft Requirements

2000
2010
2020
2030

Solar Cycle 24

Human Mission Design

Return to the Moon

On to Mars

ACE
Follow-on Particle and Upwind Plasma Monitors
Follow-on Solar Monitors

GOES Particle Monitors

GOES SXI

Follow-on Particle and Upwind Plasma Monitors

Follow-on Solar Monitors

Human Mission Design

Return to the Moon

On to Mars

Follow-on Particle and Upwind Plasma Monitors

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GOES SXI

ACE

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2020
2030
## Operational vs. Research Spacecraft and Instruments

### Operational

- **Focus is on operational decision support**
  - Validated and verified
  - To sufficient
    - Accuracy
    - Reliability
    - Availability
  - In a usable form
  - In a timely fashion
- Minimal downtime for maintenance
- Failure has significant operational consequences

### Research

- **Focus is on specific science questions**
  - Validated and verified
  - High accuracy
  - As needed to support retrospective analysis
- Little to no requirement for:
  - Timeliness
  - Consistent continuous coverage
- Significant downtime can be scheduled
- Failure is a disappointment
Interagency, International, Commercial Opportunities

- **System solution is inherently interagency**
  - NASA
  - NOAA
  - NSF
  - DoD
- **Significant opportunity for international participation**
  - Spacecraft
  - Instruments
  - Models
  - Communications support
- **Potential roles for commercial involvement**
  - Develop models
  - Provide instrumentation
  - Support data verification validation
  - Perhaps even End-to-End “Acu-Space-Radiation-Weather” support services
Operational Requirements

• Who is responsible for developing the operational requirements for the space weather architecture?
• Beyond the science community, who is the advocate for *operational*:
  – High-cadence chronographs
  – Stereo observations
  – Far-side monitors
  – Multiple heliospheric monitors
Proposed Study

- A challenge NASA faces is to follow the pending heliophysics missions with operationally useful space weather spacecraft in time to support lunar missions.
- If NASA does not address this issue up front from a systems perspective, then a less-than-optimal architecture will be in place during the lunar missions.
- NASA should begin a study on options for operational space weather architectures to support the exploration program.
- Elements of the study should include:
  - Needs and constraints of operational exploration missions
  - Current use of both operational and Space Science assets in operational forecasts
  - Trends of space weather theory and models
  - Goals of the pending space weather science missions
  - Realistic timeframes for acquisition of new operational assets
- Output of the study should include three notional architectures:
  - "status quo" (extending today’s capability into the future)
  - "modestly evolutionary" (improved operations reflecting current state of the art)
  - "breakthrough" (what might be deployed incorporating expected findings from planned missions)
Conclusions

• Important time for radiation protection, with advances underway in physics, biology, and increased complexity of missions
• Need for quantification of benefits beyond ALARA
• Need for operators, biologists, physicists, and others to work together to define optimal system approach
• Time is right to lay the groundwork for an effective radiation protection architecture
  – Science-based understanding
  – Operational instruments and models
  – Interagency, International, and Commercial Opportunities
Backup Slides
Radiation Risk Management Investment Strategy

Step One: Strategic Decisions

Radiation Limits:
• Lifetime
• Annual
• 30-Day
• Peak Dose Rate?

Radiation Risk Management Strategy:
• Cope and Avoid
• Anticipate and React

Biological Effects Including Uncertainty

Risk Philosophy
Radiation Risk Management Investment Strategy
Step Two: Mission Design Concept

Mission Architecture Elements
• Spacecraft
• Habitat
• Rover
• Suit (space and surface)

Radiation Architecture Elements
• Shielding
• Dosimeters
• Concept of surface operations
• Space weather architecture
Radiation Risk Management Investment Strategy
Step Three: Transit Phase Shielding Analysis

- GCR Models
- SPE Climatology
- SPE Worst Case
- Nuclear Cross Section Database
- Shielding Studies
- In Situ Validation
- Biological Effects Including Uncertainty
- Risk Philosophy

Design Reference Mission

Anticipated Exposure Including Uncertainty

Transport Code Development

Spacecraft Shielding
- Mass
- Distribution
- Composition

Transport Analysis Including Uncertainty

- Dose Estimate
- Peak Dose Rate Estimate

Within Limits?

- Yes
- No

Modify Shielding

Final Mission Design

Mission Limits

Biological Weighting Factors
Radiation Risk Management Investment Strategy
Step Four: Surface Operations Concept Development

Shielding Analysis for Habitat, Rover, Suits

Baseline Space Weather Nowcast/Forecast Elements

Integrated Surface Operations Plan

Adjust Surface Operations Plan

Dose Estimate

Peak Dose Rate Estimate

ALARA?

Yes

Final Concept of Surface Operations

No

Metrics affecting “Reasonable”

- Cost
- Probability of mission success
- Operational flexibility
- Implicit risk in other areas

ALARA:
As Low As Reasonably Achievable
Radiation Risk Management Investment Strategy
Baseline Space Weather Nowcast/Forecast Elements

- Solar Imager(s)
- Heliosphere Monitor(s)
- Particle Environment Monitor(s)
- Dose and Dose Rate Monitor(s)
- Physical Models
- Communications
- Adjust Architecture

- Nowcast
- Forecast
- Reliable
- Timely
- Complete

Metrics Affecting “Performance”
- Cost
- Accuracy/Precision
- Timeliness
- Reliability
- Availability