Orion Exploration Mission 1: Proposed Radiation Measurements in Cislunar Space

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Orion MPCV

- Orion is an Exploration Class spacecraft
  - Designed for Exo-LEO (not geomagnetically shielded) radiation environment

- European Service Module for EM-1 and EM-2
  - Collaboration with Airbus/ESA

- Crew Ionizing Radiation Protection
  - First standalone spacecraft to incorporate crew radiation protection in the early design
    - Consistent with ALARA (As Low As Reasonably Achievable) principles
  - Radiation analysis is performed on the full detail, manufacturing quality CAD model of the spacecraft
    - Iterative process, performed by the contractor integral to the design engineering effort
  - Orion radiation protection solution evolved with the vehicle design trade space
    - Lift-off mass is an important design driver
    - Successful crew radiation protection strategy was enabled by familiarity with vehicle design and optimization of radiation analysis procedure
  - Current baseline improves the crew protection (i.e., reduces exposure) by a factor of ~3x, down to E ~ 100 mSv / Design reference SPE (King Aug ‘72)
## SPE Response Scenario

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2016</th>
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<tbody>
<tr>
<td>Safe haven</td>
<td>Safe haven partially in the bays</td>
<td>Safe haven completely in the bays</td>
</tr>
<tr>
<td></td>
<td>Cabin reconfigured to optimize shielding</td>
<td>Cabin reconfigured to optimize shielding</td>
</tr>
<tr>
<td>Radiation</td>
<td>216 kg of dedicated radiation shield</td>
<td>0 kg of dedicated radiation shielding</td>
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Nominal Cabin Configuration
Cabin Reconfigured for SPE
Radiation Shelter Evaluation

- NASA JSC Building 9
- Orion medium-fidelity mockup
- July-Aug 2016
Exploration Architectures

• Additional Exploration capabilities beyond Orion and SLS

• NASA NextSTEP program: development of deep space habitation
  – NASA anticipates first flight opportunities in Early to Mid 2020s
  – Lockheed Martin has participated in Phase 1 and has been selected for Phase 2
    • Goal of phase 2 is delivery of ground prototype units to NASA

• Expanded vision for crew radiation protection
  – Leverage Orion lessons learned
    • Early design for radiation protection
    • Shielding augmentation by repurposed mass
    • Radiation analysis as enabler of ALARA
  – New strategies
    • Emphasis on mobility and portability between elements
    • Individual SPE radiation shield (vest)
AstroRad Radiation Vest

• **International Collaboration** Lockheed Martin & StemRad
  – Leverages StemRad manufacturing expertise
  – Analysis shows ~2x increase in protection
    • SPE, Orion-representative shielding, vest mass = 26 kg
  – Ergonomic evaluation in the Orion & ISS mock-ups
• Electronic components are susceptible to ionizing radiation too!

• Orion RHA effort is of unprecedented complexity
  – Modern EEE parts in a complex software configurable Avionics system
  – 120 V power system
  – Exo-LEO environments
  – Safety requirements
  – Dynamic mission phases
  – International collaboration (ESA/Airbus)

• First ever NASA spacecraft to implement an Ionizing Radiation Control Plan (IRCP)
  – Contractual document that imposes a uniform set of ionizing radiation requirements across components / providers
  – EEE Parts radiation testing: LET, sample size, particle range, similarity, derating
  – SEE circuit analysis in Radiation Assessment Matrix (RAM)
    • TID is secondary concern

• System integration of radiation effects
Exploration Flight Test 1

- Two-orbit flight successfully completed Dec 5, 2014
- High altitude, high eccentricity orbit to max altitude 3,600 mi
- Van Allen proton belts environment was modeled with AP-8
  - Intravehicular peak flux comparable to the design reference Oct ‘89 SPE
- **Dynamic environment**
  - Second stage jettison “SM separation” occurred close to peak flux environment
Radiation Area Monitors

- Passive Dosimeters (OSLDs)
  - Incorporated in the vehicle as an Opportunity (no associated requirements)
  - Provided & processed by NASA SRAG
  - Pre-flight intravehicular environment predictions by Lockheed Martin agree w/ measurements within factors 0.96-1.4x

![Graph showing radiation dose comparison between predicted and measured data for various RAM locations.]

**RAM locations**

- RAM1: CIAS pallet
- RAM2: aft bulkhead, ctrl stowage bay
- RAM3: aft bulkhead, WMS
- RAM4: fwd bulkhead inside tunnel
- RAM5: conical section, thick shielding
- RAM6: conical section, thin shielding
Exploration Design Challenge

• Education outreach initiative of NASA, LM, and NIA
  – Space radiation shielding design by high school team was flown on EFT-1
  – OSLDs for EDC were provided courtesy of Oklahoma State University
    • Credit: Brandon Doull, Eduardo Yukihara
EFT-1 Flight Test Camera

Predicted proton flux (AP-8, E > 50 MeV)

mission elapsed time (hh:mm)
EFT-1 Flight Test Camera

Predicted proton flux (AP-8, E > 50 MeV)

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EFT-1 Flight Test Camera

Predicted proton flux (AP-8, E > 50 MeV)

mission elapsed time (hh:mm)
Exploration Mission 1

Total Mission Duration: 25-26 days

Return (DRI to EI): 8-11 days

Outbound (TLI to DRI): 8-11 days

1) Launch

2) Perigee Raise Maneuver (PRM)
   ICPS - 100x975 nmi
   (185x1806 km)

3) Trans-Lunar Injection (TLI)
   ICPS

4) OTC-1/possible OMS-E Check Out (OCO) burn
   Orion OMS-E/Aux

5,7) Outbound Trajectory Correction (OTC) burns 2 thru 6
    Orion Aux

6) Outbound Powered Flyby (OPF) burn
   Orion OMS-E/Aux

10) Distant Retrograde orbit Departure (DRD) burn
    Orion OMS-E

11,13) Return Trajectory Correction (RTC) burns 1 thru 6
       Orion Aux

9) Orbit Maintenance (OM) burns
   Orion Aux

8) Distant Retrograde orbit Insertion (DRI) burn
   Orion OMS-E

12) Return Powered Flyby (RPF) burn
    Orion OMS-E

14) CM/SM Sep
    EI-20 min

15) Entry & Landing

Outbound (TLI to DRI): 8-11 days

Distant Retrograde Orbit (DRO): 6 days
37,797 nmi
(70,000 km)

Total Mission Duration: 25-26 days
EM-1 Radiation Measurements

- Radiation phantoms to offset ballast and add science value
  - Two RANDO phantoms provided by DLR and ISA
  - ISA phantom fitted with the AstroRad vest
  - Opportunity for international dosimetry intercomparison

EM-1 provides a unique opportunity for exo-LEO anthropomorphic phantom dosimetry inside a human rated spacecraft
Ground Rules

• **Vehicle Integration**
  – Phantom location will be driven by vehicle constraints (Mass Properties)
  – No impacts to the vehicle
    • Payload restraint engineering
    • No power or data assumed available from the vehicle
  – Rely on payload provider for Flight Certification
    • Focus on Safety / Hazard Review (e.g., loads, vibration, outgassing, thermal)
    • Inputs required for vehicle level analyses
  – Internal cabin environment:
    • Pressure: 14 to 18 psia nominal (0 psia contingency)
    • Temperature: -7 ºC to +45 ºC (19 ºF to 117 ºF) (bounding extreme range)

• **Science component**
  – Passive dosimetry with large international involvement
  – Active dosimetry highly desired subject to integration constraints
    • Self contained power/memory/switch-on, additional flight certification (thermal, batteries)
    • Separate environment contributions (van Allen / Solar protons vs. GCR)
    • Local measurements to assess AstroRad shielding effectiveness
  – CAD shielding analysis & environmental predictions
  – Science data are to be published in major peer-reviewed journal(s)
Conclusion

Your help is requested:
• Support/participate in the EM-1 radiation phantom dosimetry intercomparison
• Identify/ provide active dosimetry for the EM-1 radiation phantom measurement
• Suggest other science experiments on EM-1 (radiation- or non-radiation)

Ultimate goal is improving astronaut safety and enabling Exploration