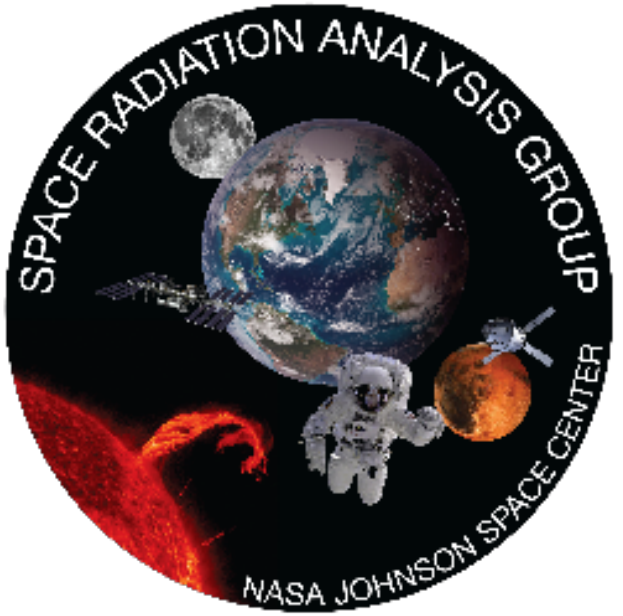
Space Radiation Protection during NASA Exploration Class Missions



Kerry Lee
Space Radiation Analysis Group Operations Lead
NASA Johnson Space Center
Houston, TX

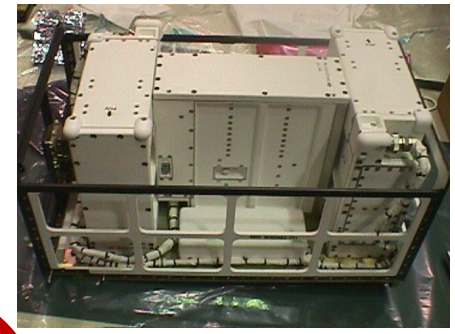
Outline

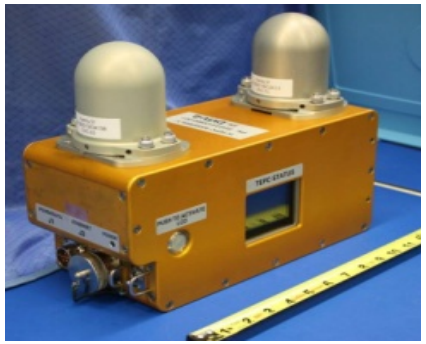
- SRAG Operations and Instrumentation on ISS
  - SRAG's purpose is to protect astronauts from radiation exposure
- Exploration Missions and Operations
  - Measurements vs Model
  - Radiation Hazard Mitigation Planning
- MPCV* Radiation System Sensors
- Space Weather Needs for Exploration Class missions

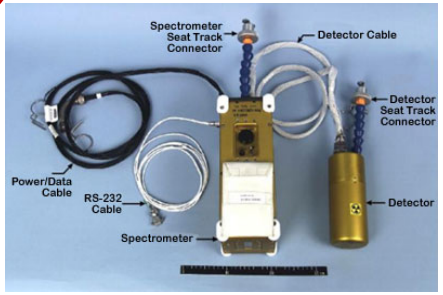
*Orion = MPCV = Multi-Purpose Crew Vehicle

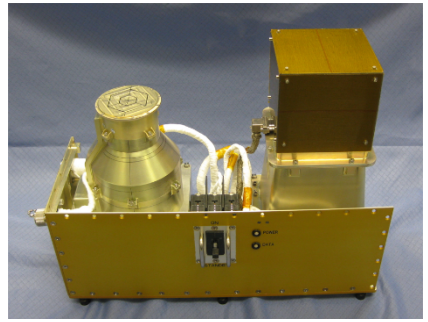
ISS Instrumentation

- CPDS – Charged Particle Directional Spectrometer
- **REM – Radiation Environment Monitor**
  - Active dosimeter with USB interface
- TEPC – Tissue Equivalent Proportional Counter
  - Located in ISS Service Module
- IV-TEPC – new TEPC detector
  - Moves about ISS every 4-6 weeks
- ISS-RAD – Radiation Assessment Detector





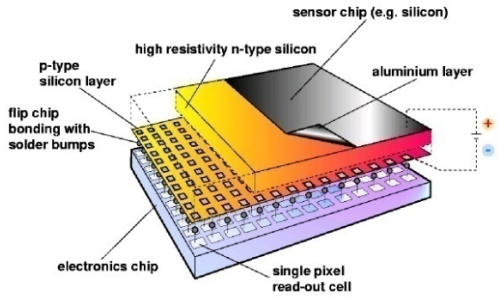


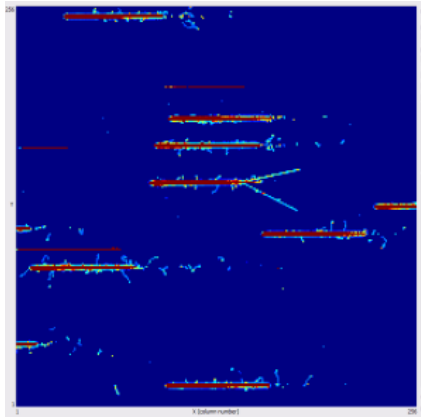


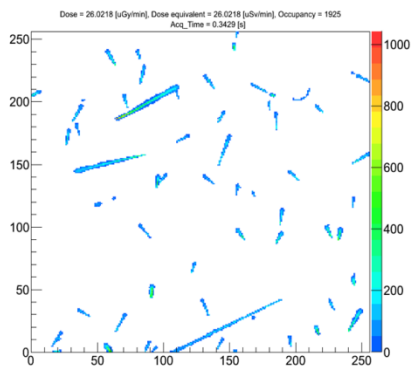
Radiation Environment Monitor (REM)

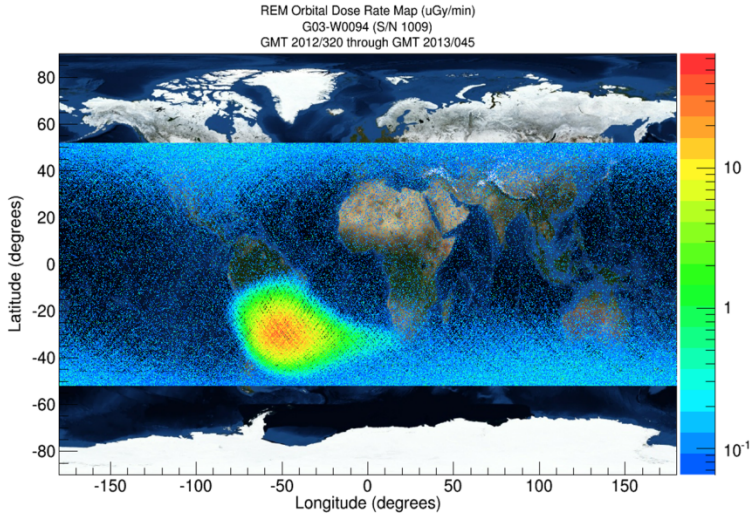
The Timepix Detector

- Developed as a High Energy Physics application of medical imaging technology
- Hybrid Pixel Detector with independent counting and readout circuitry in each pixel footprint
- 256 x 256 pixel grid with total area of 2 cm^2





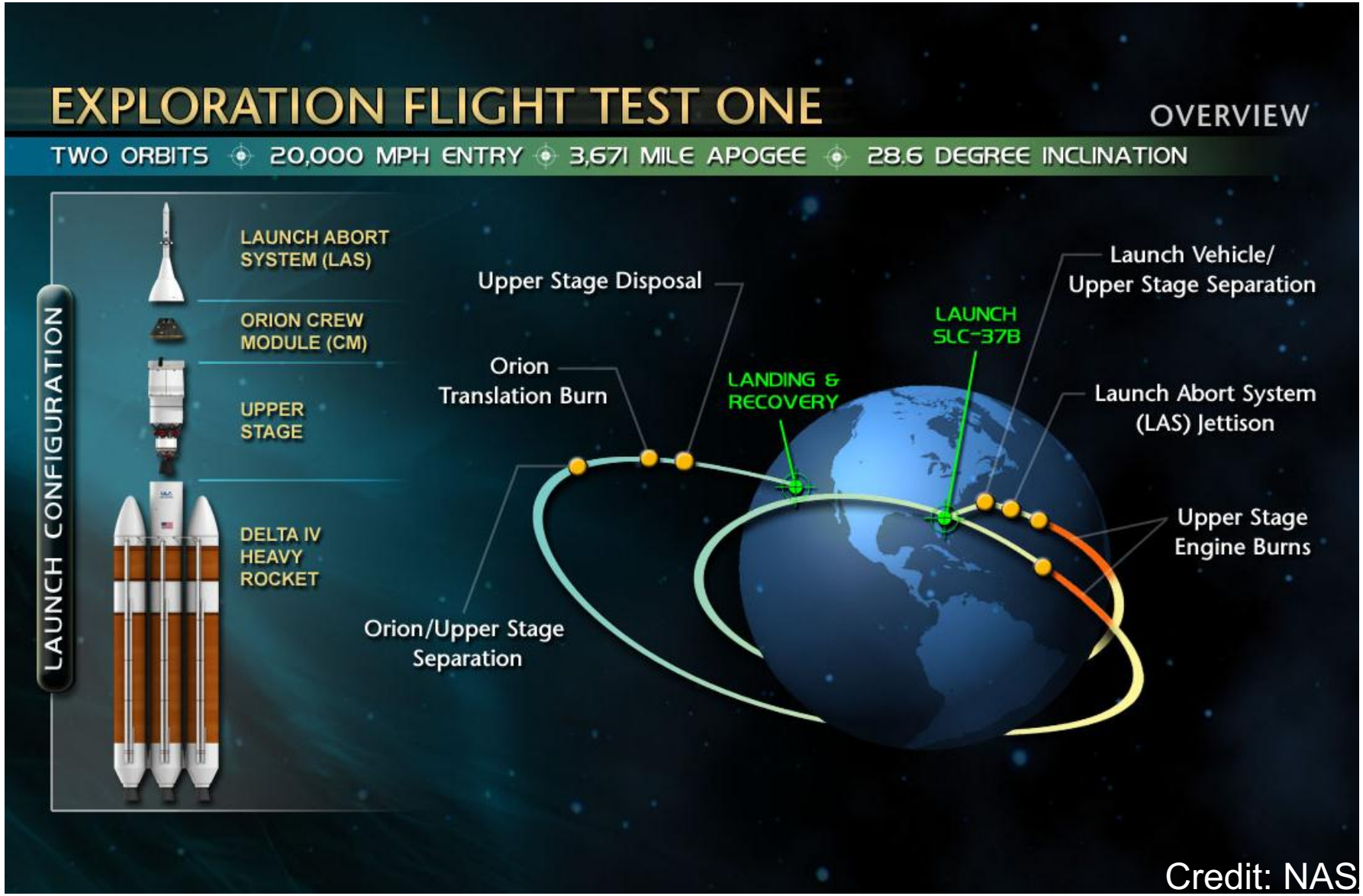


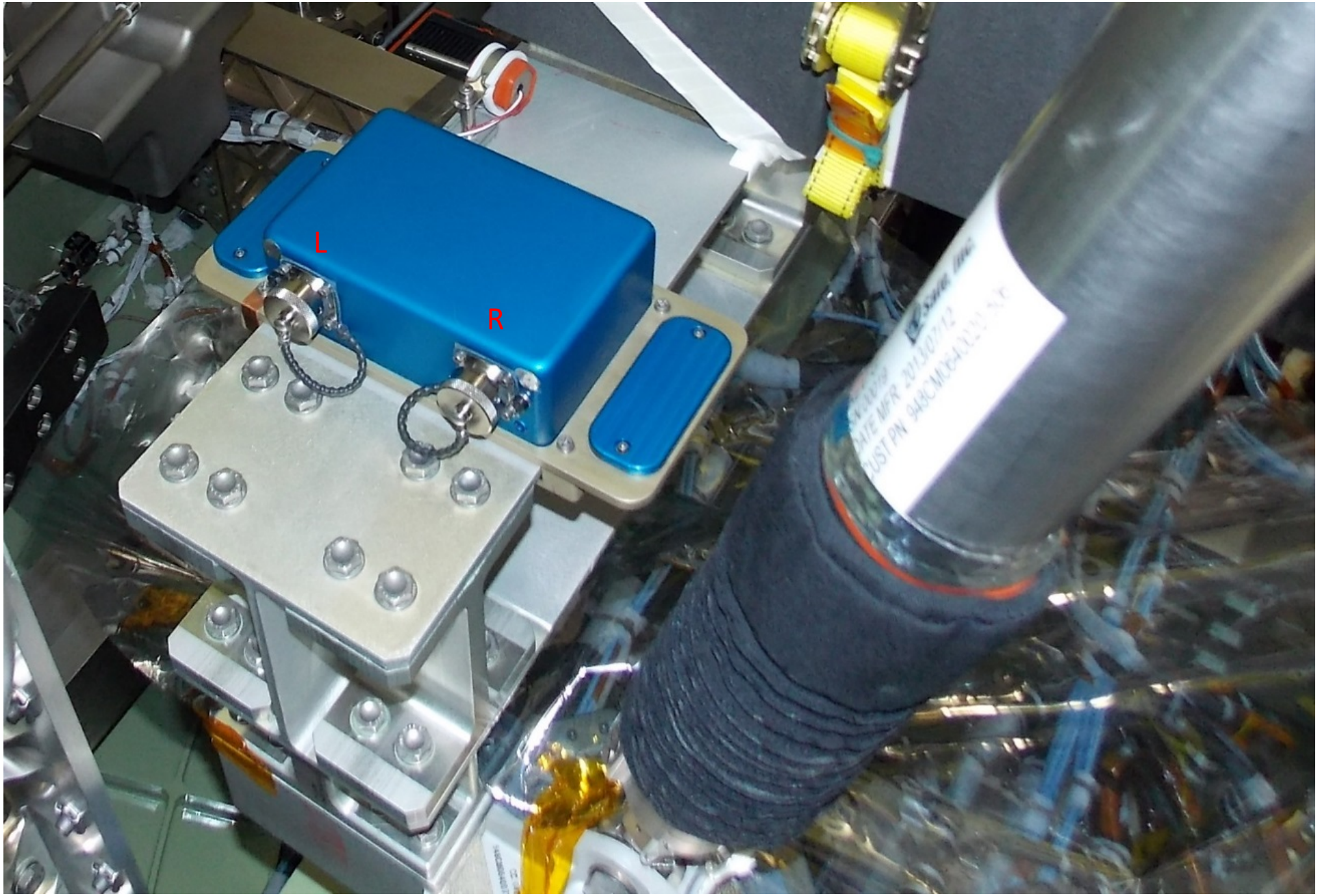


Pixel Detector Image from Medipix collaboration website: http://medipix.web.cern.ch/medipix/img/medipix2/web_flipchip.gif

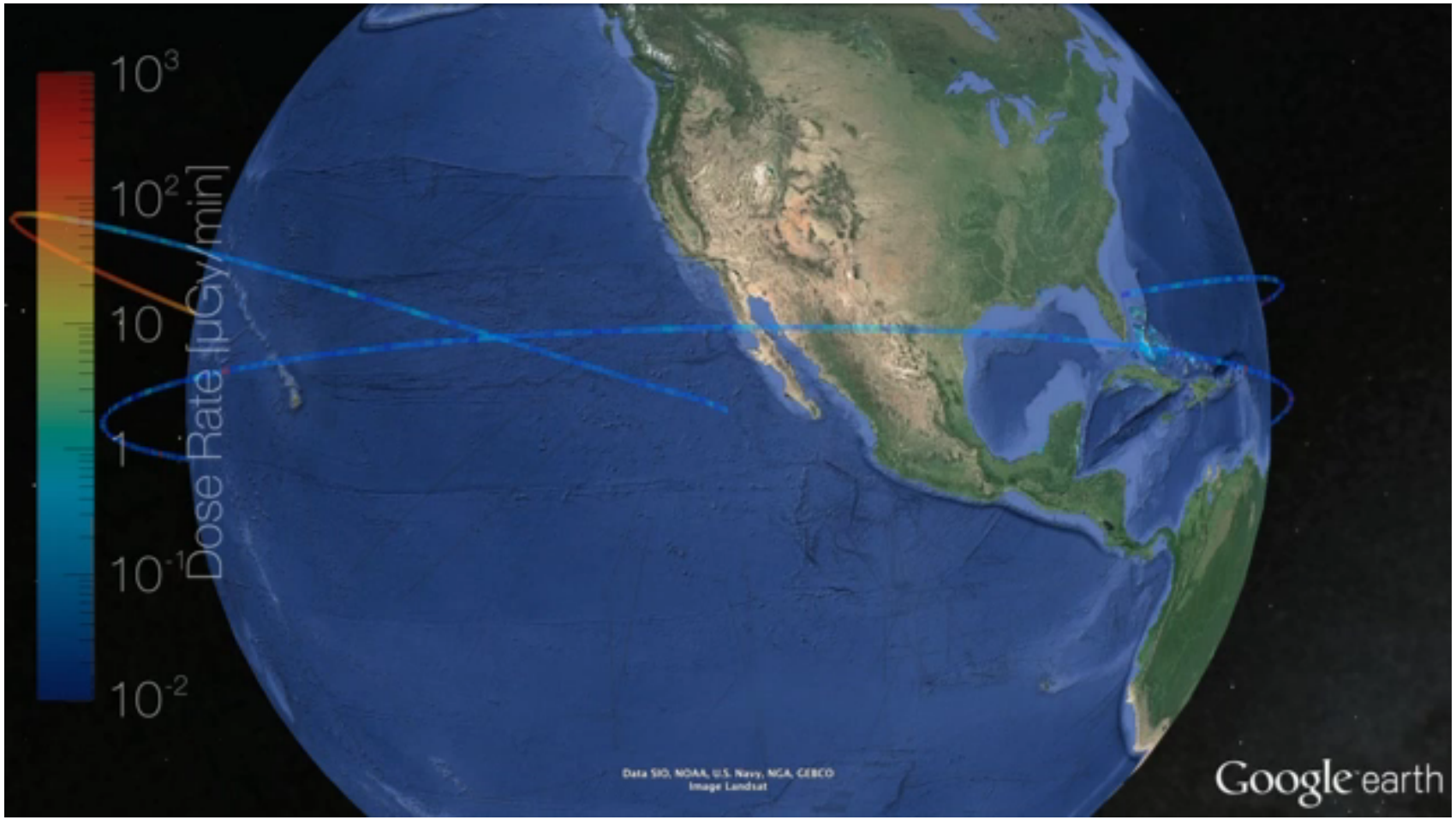
Exploration Mission (EM) Class Measurements and Simulation

Exploration Flight Test 1 – Dec 5, 2014




L
R

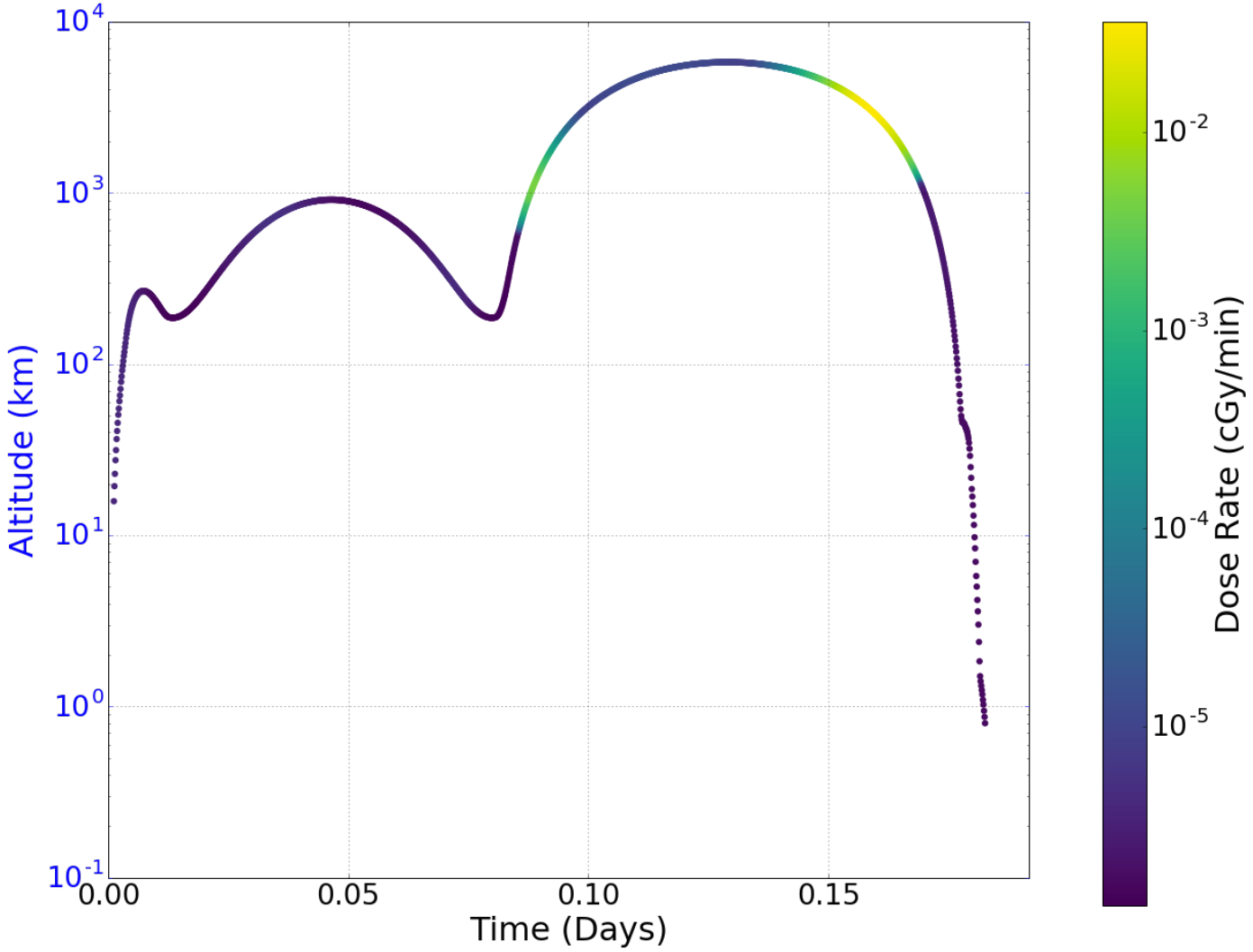
Google Earth Video – EFT-1 Flight



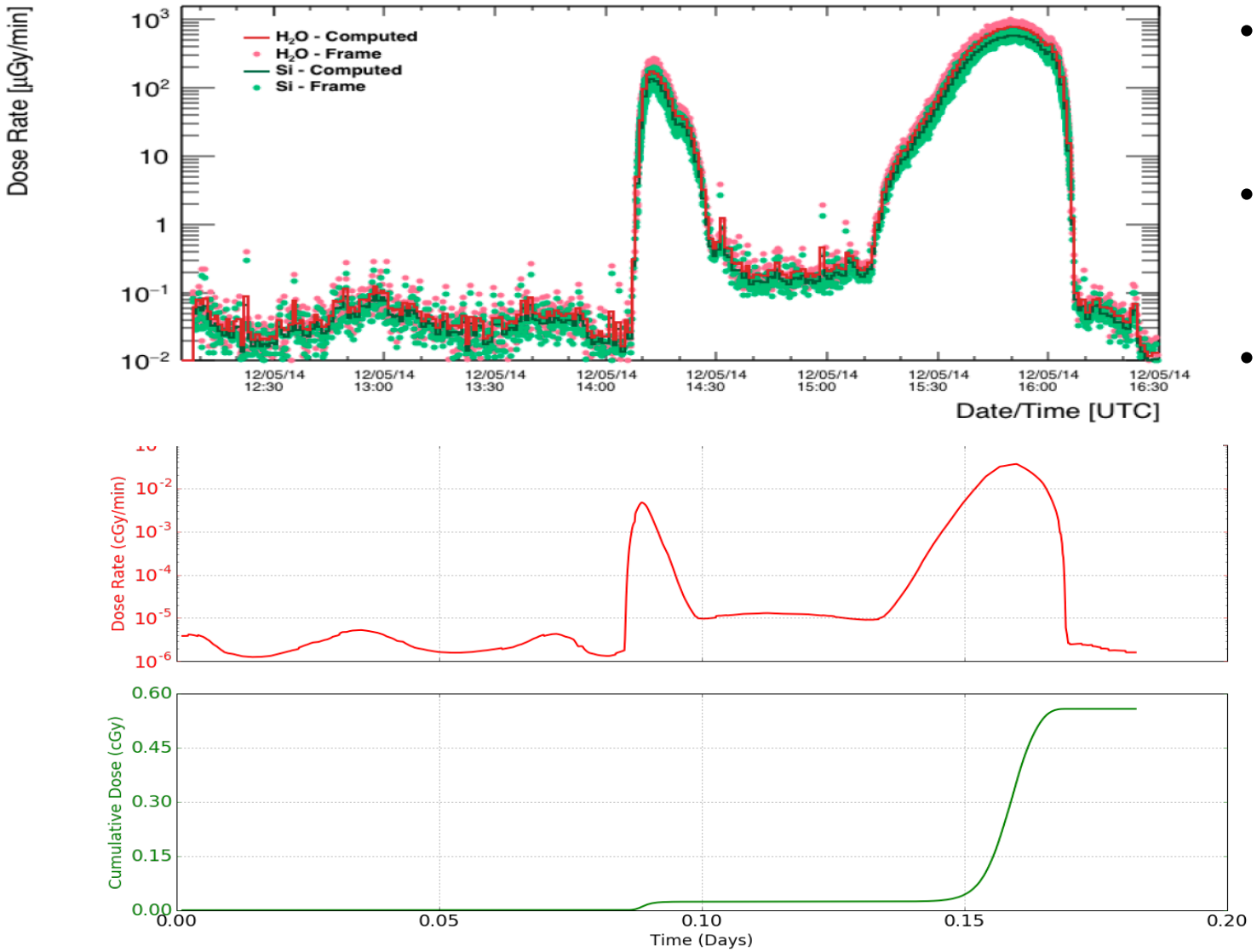
EFT-1 Mission Analysis

- Trajectory: EFT-1 Approximated Trajectory
- Shields: Full vehicle CAD model
  - Points: BIRD RAMs 1 and 2, BIRD Detectors Left and Right
- Trapped Radiation: AP8/AE8 Model
- GCR: Badhwar-O'Neill 2014 Model, December 5, 2014
- Radiation Transport: HZETRN2015

BIRD Left Model

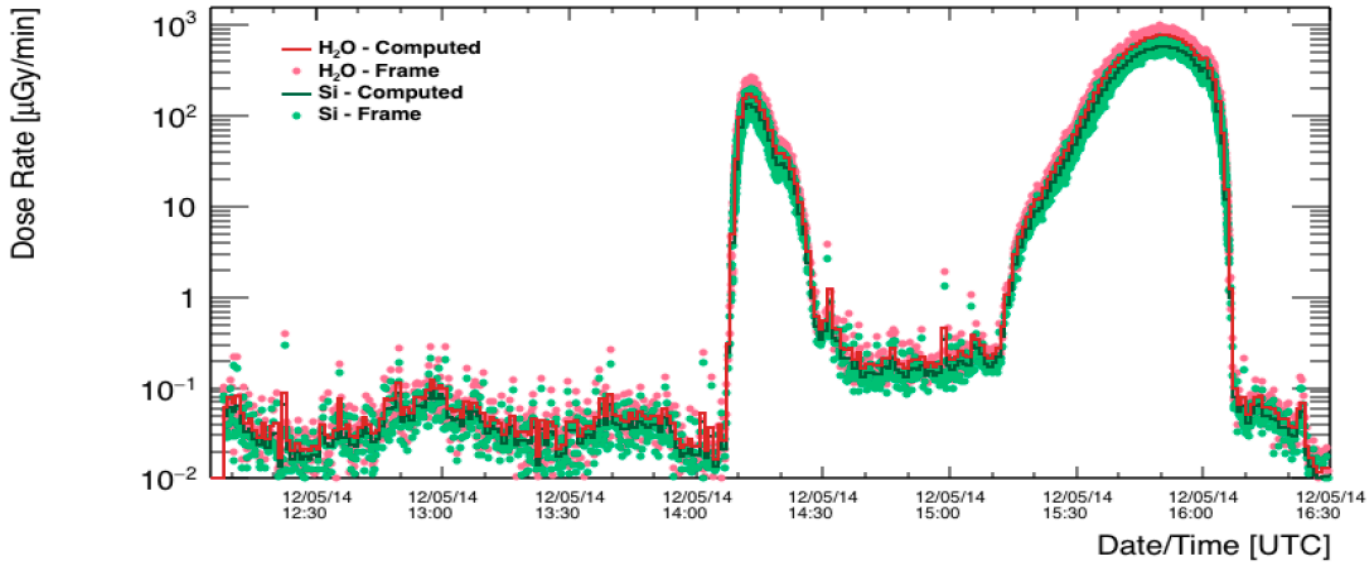


BIRD Left Model vs Data



- Data is in microGy and model in cGy
  - 4 orders magnitude difference
- Model slightly under predicts GCR regions
  - 10s of percent
- Model significantly under predicts trapped radiation regions
  - Factor of 2 -3

Model vs Data for each EFT-1 Measurement



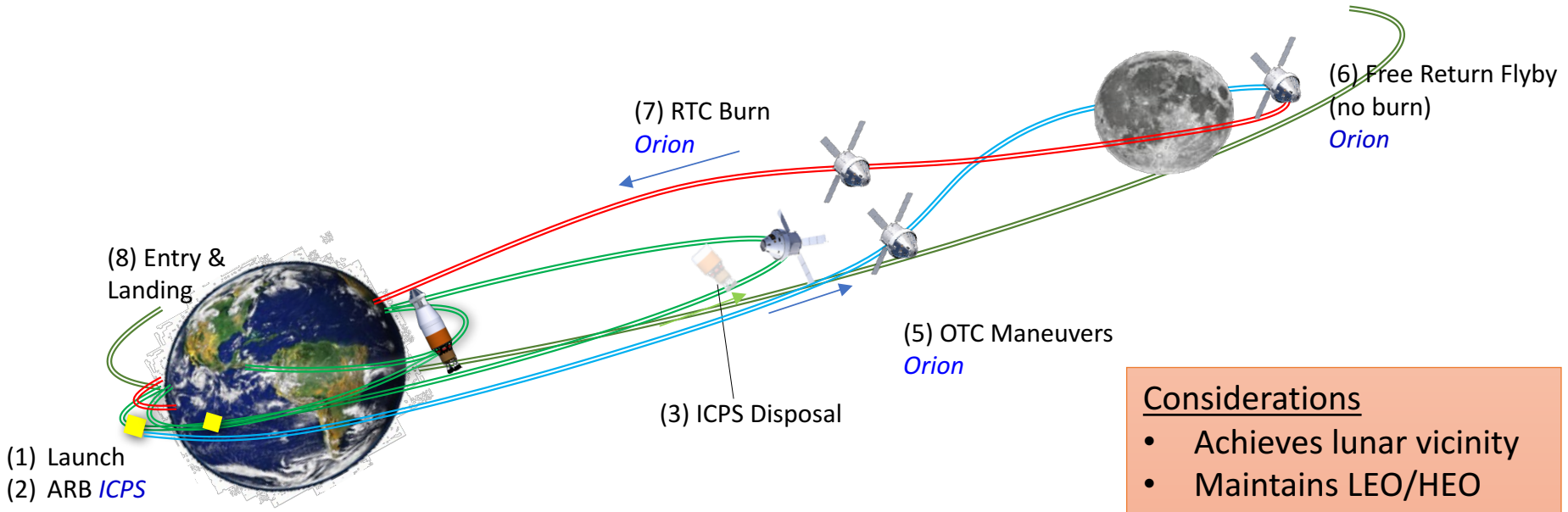
Shield File	Modeled (mGy)	Measured (mGy)
BIRD Left	5.57	17.9
BIRD Right	5.94	15.7
BIRD RAM1	6.81	15.1
BIRD RAM2	6.18	13.5

EM-2 Mission Analysis

- Trajectory: Hybrid Triple
- Shield Point: Crew 1 Chest Location in Orion Seat 1 of EM-2 Vehicle
- Trapped: AP8/AE8
- GCR: Badhwar-O'Neill 2014, August 2010
  - Expected to be similar to August 2021 which is EM2 schedule launch date
- Radiation Transport: HZETRN2015

EM-2 Mission Option: Free Return Hybrid Triple

Notional



1-2) LEO parking orbit, 1-2 orbit checkout, and ICPS Apogee Raise Burn (ARB) demonstration

3) Orion separates after ARB, achieves safe separation distance, ICPS performs disposal burn

4) Orion flight test system characterization occurs in HEO (16-24 hrs), TLI performed by Orion

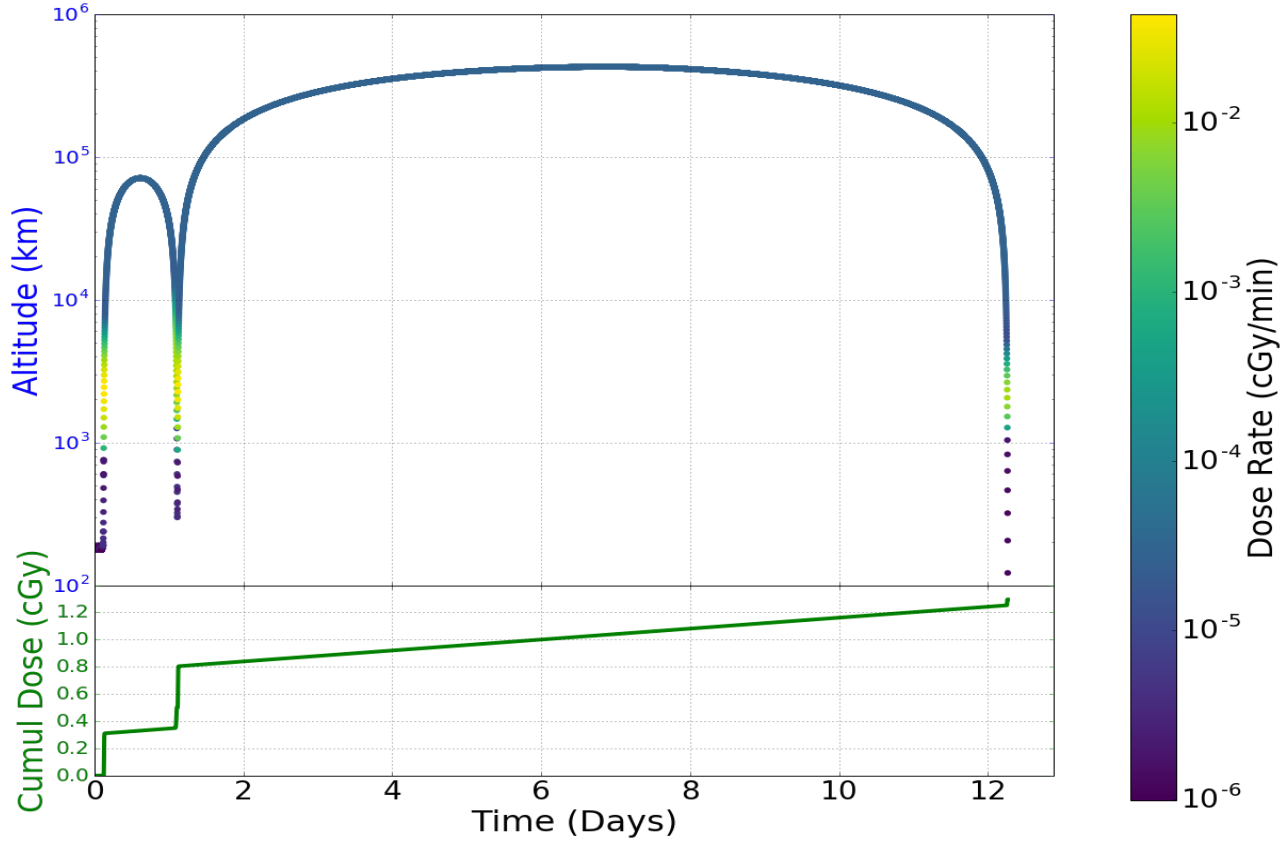
6) Free return flyby, no Orion critical burns required

8) Nominal mission return and cis-lunar entry velocity targeting San Diego vicinity

Considerations

- Achieves lunar vicinity
- Maintains LEO/HEO checkout opportunity
- Within existing Orion capabilities
- Likely within ICPS capability

EM-2 Proposed Hybrid Triple Trajectory



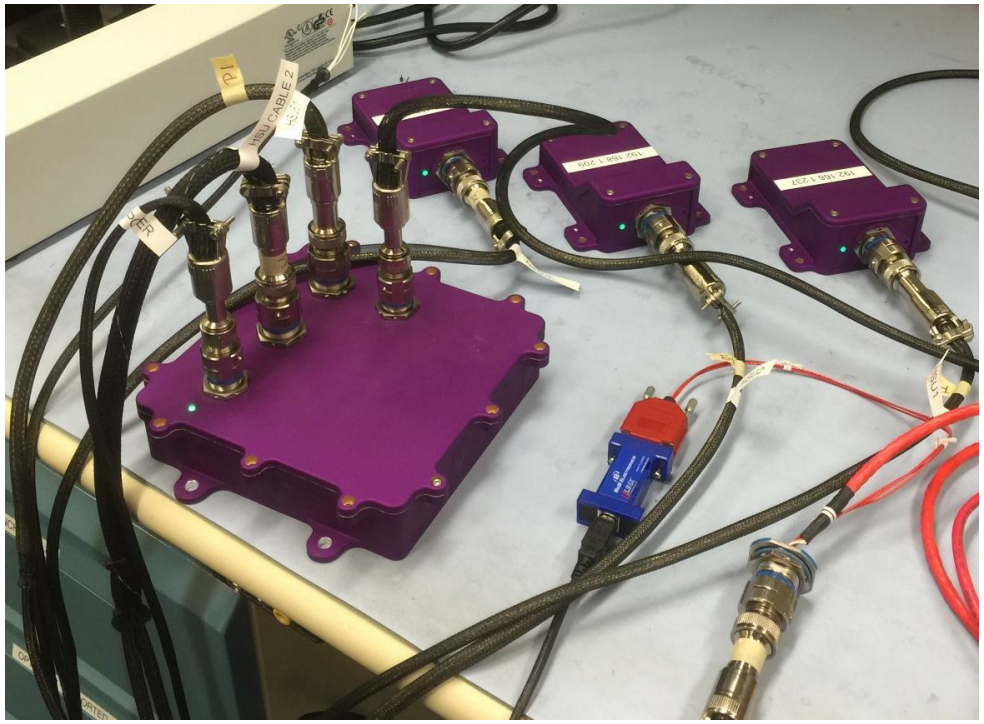
- 3 passes though trapped radiation belts contribute ~2/3 of modeled dose
- 12 days of GCR contributes ~1/3 of modeled dose

Future Exploration Mission Analyses

- Need to evaluate hundreds of potential launch trajectories covering the full launch window
  - In keeping with the ALARA principle we will recommend trajectories with the lowest exposures
- Use the best trapped environment model with the latest data (IRENE)
- Use EM-1 Mission (December 2019 launch) measurements to calibrate prediction capabilities for future EM-X missions

MPCV Radiation System

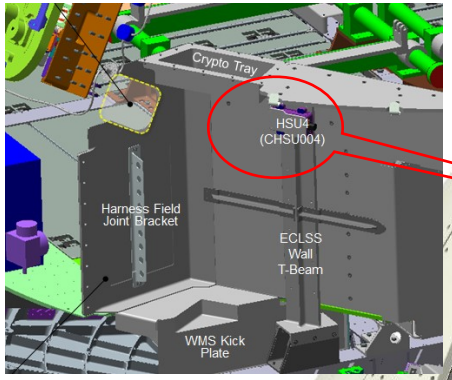
- Hybrid Electronic Radiation Assessor (HERA)
  - Active instrument provides telemetered data stream
  - System consists of two redundant strings
    - Each string - 1 Power Unit and 2 Sensor Units



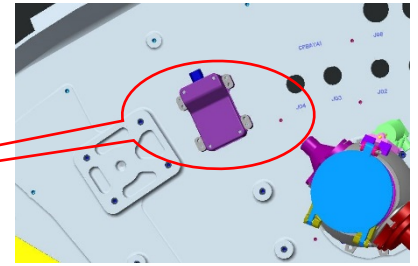
- Radiation Area Monitors (RAMs)
  - Passive detectors from Shuttle and ISS heritage

- Crew Personal Active Dosimeter (CPAD)
  - Active dosimeter provides individual dosimetric measurement
  - Data retrieved after the mission

HERA Vehicle Locations

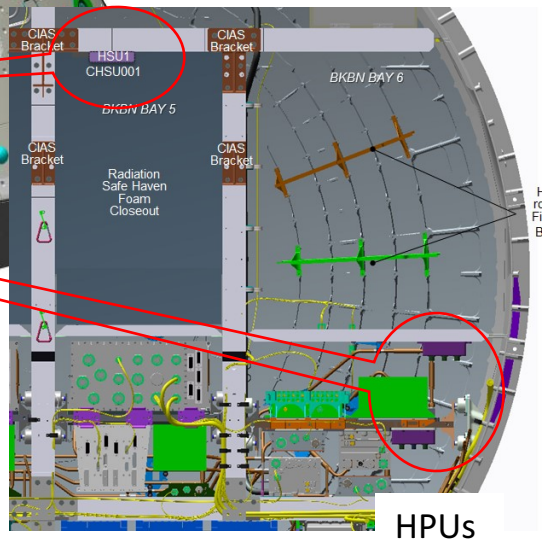


HSU Starboard

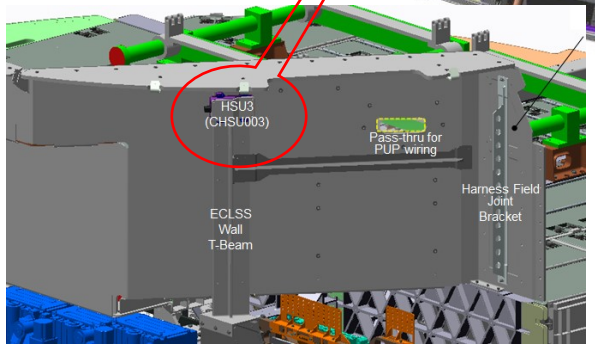


HSU Fwd Bulkhead

HSU in shelter



HPUs

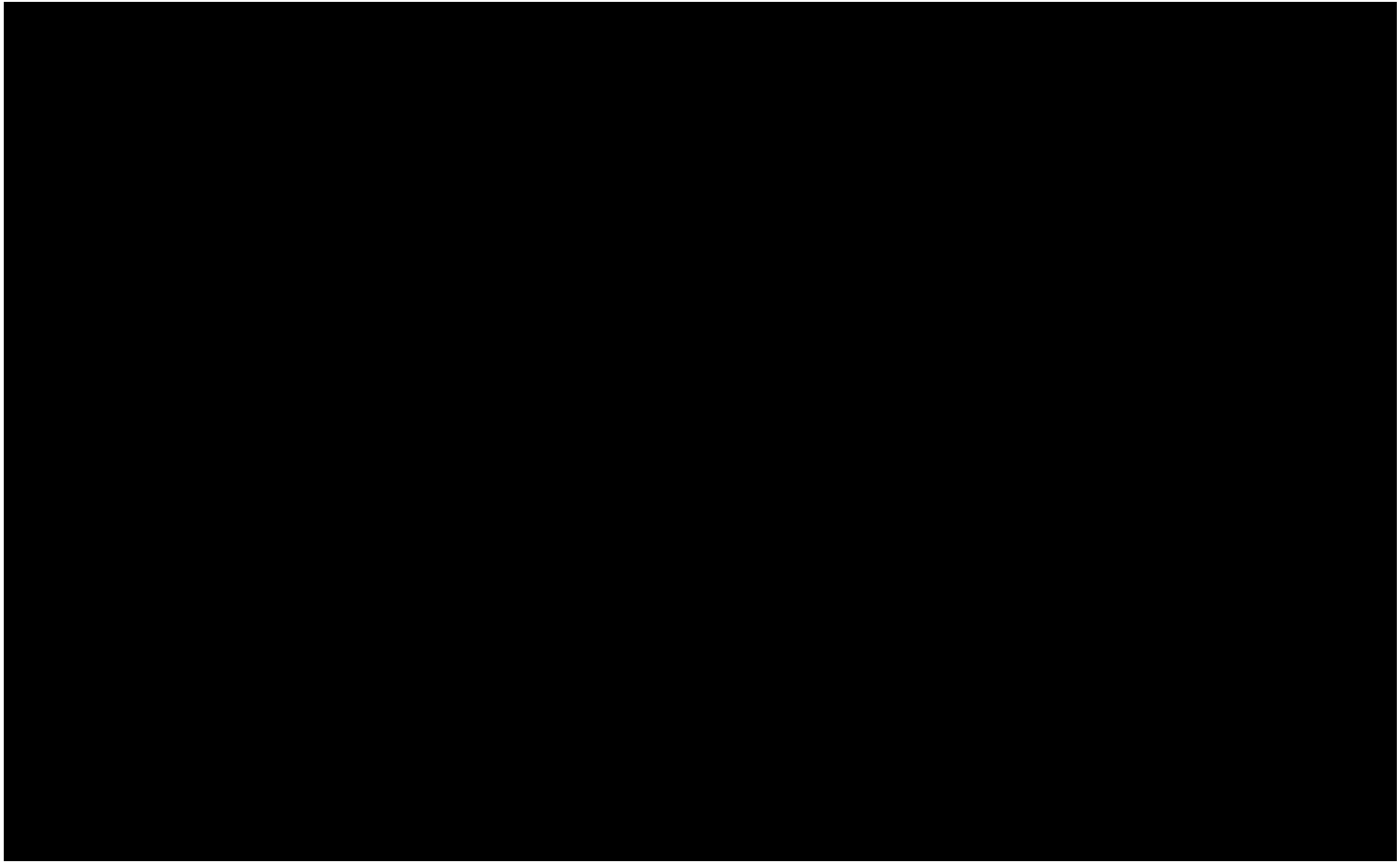


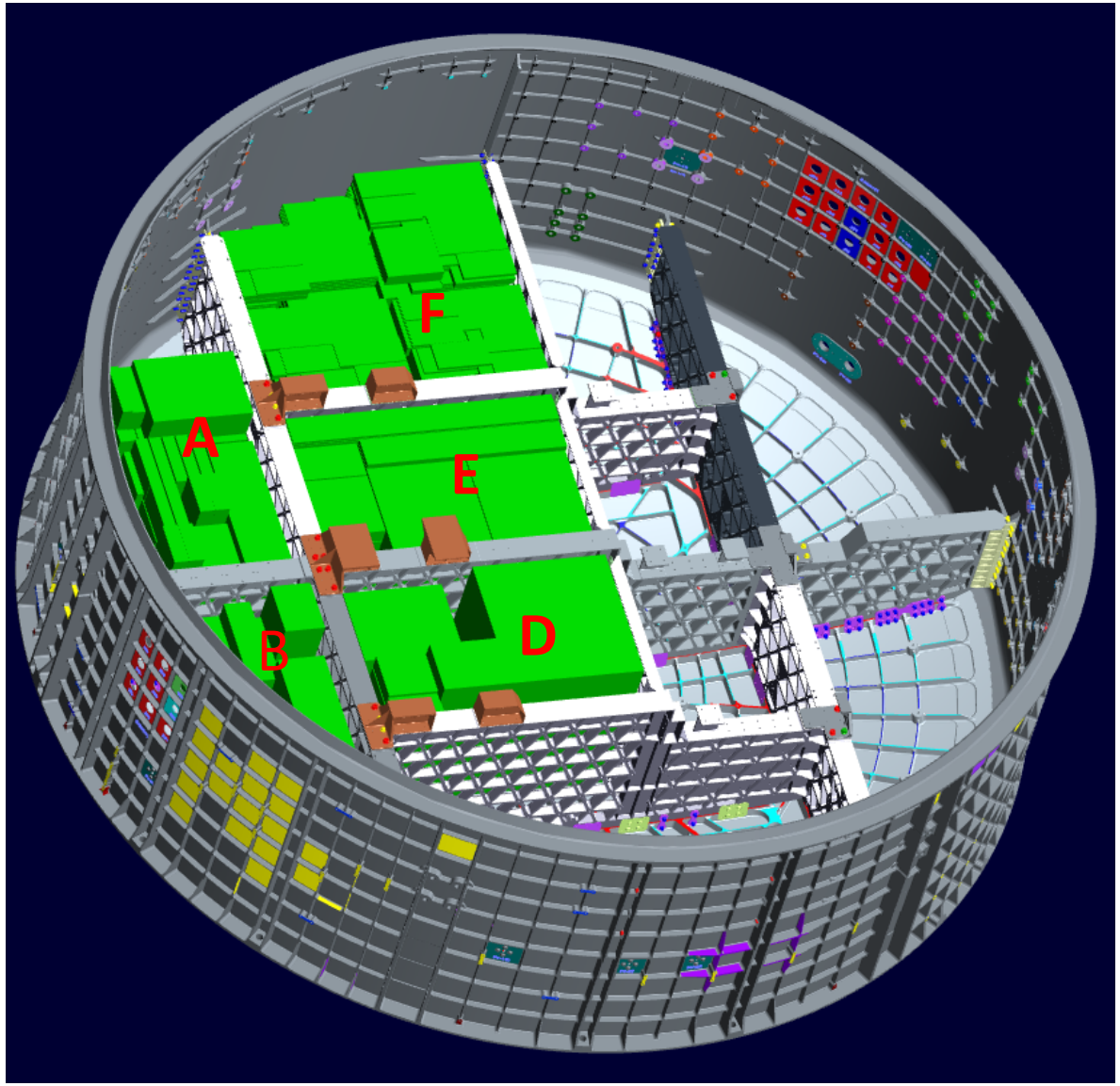
HSU Port

MPCV Radiation Mitigation Planning

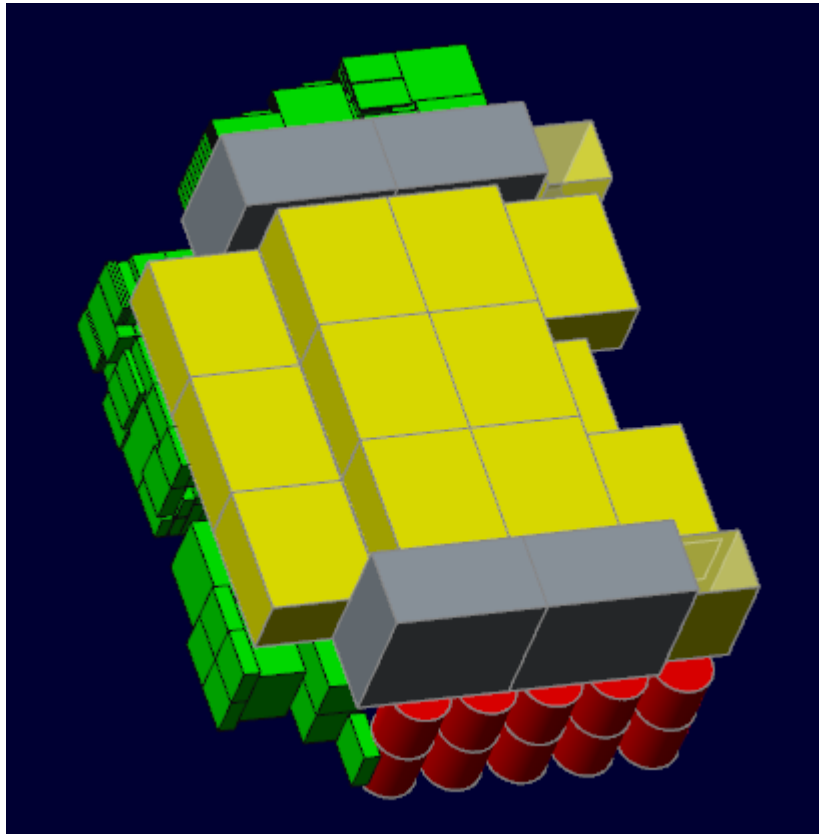
- HERA system is connected to the Caution and Warning System
  - Audible alarm sounds when HERA threshold is exceeded
  - If ground communication is available Radiation Console determines if sheltering is needed, otherwise crew will shelter upon HERA alarm
  - Acute radiation impact assessment modeled based on HERA measurements

- Stowage configuration optimized based on Human in the Loop (HITL) test
  - HITL test consisted of many simulated 4 person crews in the medium fidelity mockup at NASA/JSC
  - About half of the test subjects were astronauts
  - None of the test subjects had ever seen the procedure and most were unfamiliar with the mockup layout
  - Average time to reconfigure the cabin was about 30 minutes





Original stowage configuration



Stowage re-configuration based on HITL test

Stowage Re-configuration Model Results

- SRAG used stowage configuration used in HITL test
  - 11 CTBs and 3 half CTBs and 10 canisters (total mass = 630 lb)
    - 6 CTBs on top of backs of seats 1&2 over shelter (bays D and E)
    - 3 CTBs in front of shelter under DUs
    - One half CTB on the sides of shelter
    - Added 2 suit bags (50 lb each) on ach side of the shelter (total 4 bags of 200 lb)
    - 10 canisters (9 in OD and 9.5 in long) inside WMS on the side wall shared with Bay D

Whole Body Effective Dose* Radiation Analysis Results for a simulated 1972 King Spectrum SPE

	Crew 1	Crew 2	Crew 3	Crew 4
Crew in Seats	**208** mSv	**191** mSv	**268** mSv	**230** mSv
HITL config (630 lb + suit bags)	**69** mSv	**83** mSv	**79** mSv	**71** mSv

*Effective Dose as defined in National Council on Radiation Protection and Measurements (NCRP) Report No. 132

Summary

- Established MPCV concept of operations for radiation contingency event
  - Protection is possible below required limit without flying any parasitic mass
  - Final details are being worked
- MPCV radiation instrumentation is built
  - Hardware testing on ISS in the near future
- SRAG Operational needs for future exploration missions (in chronological order)
  - Use latest IRENE release to evaluate EM-1 and EM-2 trajectories and compare with data
  - Forecasting tools for more lead time on SPEs
    - All-clear still a valid operational method – no geomagnetic field protection for Gateway missions
  - Off Sun-Earth line SPE forecasting (all-clear)
    - Europa and Mars missions (2030s)

Acknowledgements

- Space Radiation Analysis Group – REM and HERA analysis work
  - Martin Kroupa, Stuart George, Nic Stoffle, Thomas Campbell-Ricketts, Ryan Rios

- AES Program for funding HERA development
  - Jason Crusan, Catherine Mcleod, Scott Wheeler, Michael Ecord and entire HERA development team