Overview of SRAG activities (hardware) in preparation for Artemis Operations

WRMISS
September 7, 2022

Eddie Semones – SRAG, NASA Johnson Space Center

Artemis To Do List

Radiation Operations, Hardware, and Space Weather

- Establish/Update human radiation exposure standards
  - Career/Acute-SPE/Nuclear Tech shielding updated
  - GCR shielding under review
- Review/ Pursue all relevant precursor data of space radiation environment
  - ISS lessons learned (trapped/GCR/neutron environments)- REMs/CAD/RAD/HERA/ANS
  - Chang'E Lander, CRaTER, CLPS
- Develop comprehensive set of vehicle design, radiation monitoring, forecast support requirements
  - NASA-NOAA MOU updated
  - SRAG-SWPC-M2M Summit
- Develop equipment/mitigations deemed Government Furnished Equipment (GFE)
  - HERA delivered for initial Artemis mission and being tested long term on ISS
  - Complete ARES design and Build for Gateway HALO Module
  - Complete ARES design and Build for HLS SpaceX Starship
- Establish firm relationships with vehicle vendors for design requirement verification and ALARA activities
  - Orion shelter concept is completed and Gateway HALO underway with NG
  - New Collaboration with SpaceX
- Conduct training and certification of console operators
- Complete initial ISEP Scoreboard initial versions
- Complete ARRT – (Acute Radiation Risks Tool for Exploration Missions)
- Create comprehensive Concept of Operations and Flight Rule development utilizing all assets available
- Complete a full mission support campaign of the uncrewed: Artemis 1 mission - Now Sep-Oct 2022
  - Matroshka AstroRad Radiation Experiment (MARE) Hardware Delivery
- Conduct FCT simulations of contingency events – SPEs with crew actions
- Perform mission exposure assessments to inform crew selection
  - Artemis Cadre announced in late 2020 but now all crew being considered – expect Artemis II crew announcement in ~2022 ???

OCHMO Radiation Standards

Astronaut's total career effective radiation dose (In 3001, Vol 1 Rev B)

600 mSv

Universal for all ages and sexes, 3% mean risk of cancer mortality, effective dose calculated using 35-year-old female

An individual astronaut's total career effective radiation dose due to space flight radiation exposure shall be less than **600 mSv.**

Galactic Cosmic Radiation (GCR) (under review) - achievable with ~10-15g/cm^2

For habitable space systems designed to support crew for >60 days, the program shall protect crewmembers from exposure to the galactic cosmic ray (GCR) environment to less than a NASA effective dose (as defined in 4.8.2) rate of 1.3 mSv/day for systems in free space and to less than 0.9 mSv/day for systems on planetary surfaces.

250 mSv

Solar Particle Event (SPE)

The program shall protect crewmembers from exposure to the Design Reference Solar Particle Event (SPE) Environment Proton Energy Spectrum (sum of the October 1989 events) to less than an effective dose of **250 mSv**).

20 mSv

Nuclear Technologies

Radiological exposure from nuclear technologies emitting ionizing radiation (e.g., radioisotope power systems, fission reactors, etc.) to crew members shall be less than an effective dose of **20 mSv** per mission year (prorated/extrapolated to mission durations).

Space Flight Human System Standards – NASA-STD-3001, Vol 1
Crew Career Permissible Exposure Limit for Space Flight Radiation

After iterating with the NASEM committee, the following standard was developed.

4.2.10 Space Flight Radiation Permissible Exposure Limit

An individual astronaut's total career effective radiation dose due to spaceflight radiation exposure shall be less than 600 mSv. This limit is universal for all ages and sexes.

Rationale [The total career dose limit is based on ensuring all astronauts (inclusive of all ages and sexes) remain below 3% mean risk of cancer mortality (REID) above the non-exposed baseline mean. Individual astronaut career dose includes all past spaceflight radiation exposures, plus the projected exposure for an upcoming mission.]

The 600 mSv is based on a 3% mean REID calculation for a 35-year-old female utilizing the operational NSCR2012 model with the NASA Q, never smoker parameters.

Note the 600 mSv effective dose standard is for post mission cancer. Even though the evidence does not support a limit for cardiovascular and CNS, the proposed standard is protective for Cardiovascular and CNS effects.

Based on current understanding and state of knowledge, exposure limits for

- cardiovascular disease is <500 mGy equivalent
- central nervous system (CNS) effects is < 500 mGy-Eq
  - and < 100 mGy for z > 10.

600 mSv is equivalent to

- 380 mGy-Eq for the heart
- 231 mGy for CNS organ (z < 10)
  - 6 mGy for CNS organs for Z $\geq$ 10.

NASA will continue to assess these risks and will make the appropriate updates as more knowledge is obtained.

Chang'E 4 Mission – LND Papers…

SCIENCE ADVANCES | RESEARCH ARTICLE

SPACE SCIENCES

First measurements of low-energy cosmic rays on the surface of the lunar farside from Chang'E-4 mission

Pengwei Luo[1,2], Xiaoping Zhang[1,2]*, Shuai Fu[1,2], Yong Li[1,2], Cunhui Li[3], Jinbin Cao[4]

Human activities on the lunar surface are severely constrained by the space radiation dominated by cosmic rays (CRs). Here, we report the first measurements of the low-energy (about 10 to 100 MeV/nuc) CR spectra on the lunar surface from China's Chang'E-4 (CE-4) mission around the solar minimum 24/25. The results show that for the proton, helium, CNO, and heavy-ion groups, the ratios (ratio errors) of the CE-4 fluxes to those from the near-earth spacecraft are 1.05 (0.15), 1.30 (0.18), 1.08 (0.16), and 1.24 (0.21), respectively, and to those predicted by the models [CRÈME96 and CRÈME2009] are instead [1.69 (0.17), 2.25 (0.23)], [1.66 (0.17), 1.76 (0.18)], [1.08 (0.11), 1.07 (0.11)], and [1.33 (0.18), 1.17 (0.15)]. Moreover, a notable enhancement of $^3He/^4He$ ratio is observed at ~12 MeV/nuc, and the CR dawn-dusk symmetry is confirmed. These results provide valuable insights into the CRs on the lunar farside surface and will benefit future lunar exploration.

SCIENCE ADVANCES | RESEARCH ARTICLE

PLANETARY SCIENCE

First measurements of the radiation dose on the lunar surface

Shenyi Zhang[1,2,3,4], Robert F. Wimmer-Schweingruber[1,5]*, Jia Yu[5†], Chi Wang[1], Qiang Fu[6,7], Yongliao Zou[1], Yueqiang Sun[1,2,4], Chunqin Wang[1,2,4], Donghui Hou[1,2,3,4], Stephan I. Böttcher[5], Sönke Burmeister[5], Lars Seimetz[5], Björn Schuster[5], Violetta Knierim[5], Guohong Shen[1,2,4], Bin Yuan[1,2,4], Henning Lohf[5], Jingnan Guo[5,8,9], Zigong Xu[5], Johan L. Freiherr von Forstner[5], Shrinivasrao R. Kulkarni[5], Haitao Xu[1], Changbin Xue[1], Jun Li[1], Zhe Zhang[10], He Zhang[11], Thomas Berger[12], Daniel Matthiä[12], Christine E. Hellweg[12], Xufeng Hou[13], Jinbin Cao[14], Zhen Chang[1,2,4], Binquan Zhang[1,2,4], Yuesong Chen[1], Hao Geng[1], Zida Quan[1,2,4]

Human exploration of the Moon is associated with substantial risks to astronauts from space radiation. On the surface of the Moon, this consists of the chronic exposure to galactic cosmic rays and sporadic solar particle events. The interaction of this radiation field with the lunar soil leads to a third component that consists of neutral particles, i.e., neutrons and gamma radiation. The Lunar Lander Neutrons and Dosimetry experiment aboard China's Chang'E 4 lander has made the first ever measurements of the radiation exposure to both charged and neutral particles on the lunar surface. We measured an average total absorbed dose rate in silicon of 13.2 ± 1 μGy/hour and a neutral particle dose rate of 3.1 ± 0.5 μGy/hour.

Journal of Instrumentation

Removing the dose background from radioactive sources from active dose rate measurements in the Lunar Lander Neutron & Dosimetry (LND) experiment on Chang'E 4

D. Hou[1,2,3], S. Zhang[1,2,3], J. Yu[4], R.F. Wimmer-Schweingruber[1,4], S. Burmeister[4], H. Lohf[4], B. Yuan[1,3], G. Shen[1,3], C. Wang[1,2], X. Hou[5] + Show full author list

Published 28 January 2020 • © 2020 IOP Publishing Ltd and Sissa Medialab

Journal of Instrumentation, Volume 15, January 2020

Citation D. Hou *et al* 2020 *JINST* **15** P01032

+ Article information

Table 1. Summary of measurements of the radiation dose rate measured in μGy/hour on the lunar surface. The errors of the background dose rate from the RTG/RHUs (*20*) are considered systematic errors and have been added quadratically when reporting the final values in the rightmost column.

Dose rate (μGy/hour)	Measured	Background	Final in Si
Total	18.4 ± 0.4	5.2 ± 0.6	13.2 ± 0.7
Neutral	4.7 ± 0.1	1.7 ± 0.5	3.1 ± 0.5
Charged	13.7 ± 0.4	3.5 ± 0.8	10.2 ± 0.9

ASTROBOTIC

LETS – CLPS

Linear Energy Transfer Spectrometer

MISSION 1 | PEREGRINE

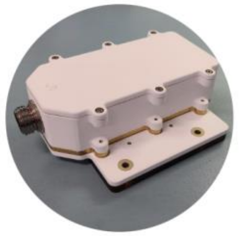
LACUS MORTIS 2022

Astrobotic's Peregrine Mission One (PM1) is poised to be the first commercial mission to land on another planetary body. With this flight, Astrobotic is opening the door to the next phase of space science, exploration, and commerce on the Moon and beyond. Peregrine will carry a diverse suite of scientific instruments, technologies, mementos, and other payloads from six different countries, dozens of science teams, and hundreds of individuals.

ASTROBOTIC PEREGRINE LANDER

SCIENTIFIC INSTRUMENT

AGENCIA ESPACIAL MEXICANA (AEM)
MEXICO

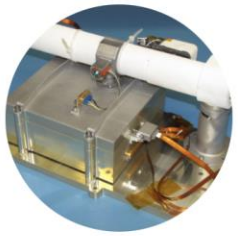


LINEAR ENERGY TRANSFER SPECTROMETER (LETS)

NASA
USA

MEMENTOS TO THE MOON

DHL MOONBOX
GERMANY



FLUXGATE MAGNETOMETER (MAG)

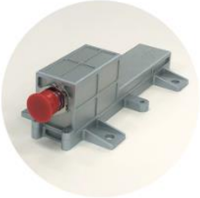
NASA
USA

ASAGUMO ROVER

SPACEBIT
UNITED KINGDOM

MASS SPECTROMETER OBSERVING LUNAR OPERATIONS (MSOLO)

NASA
USA



M-42 RADIATION DETECTOR

GERMAN AEROSPACE CENTER (DLR)
GERMANY

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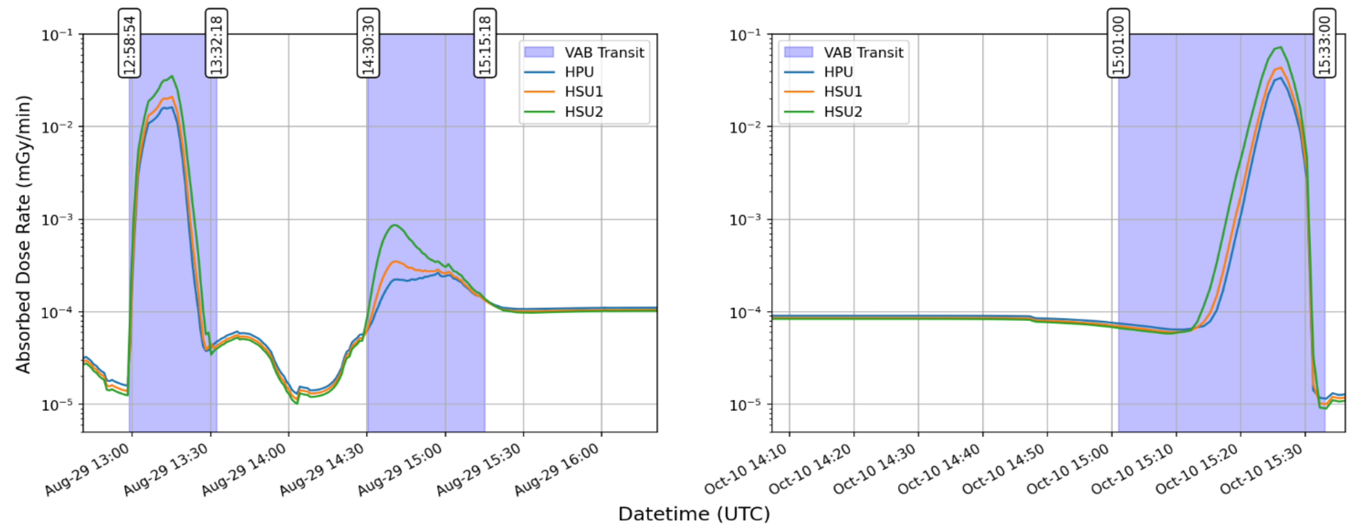
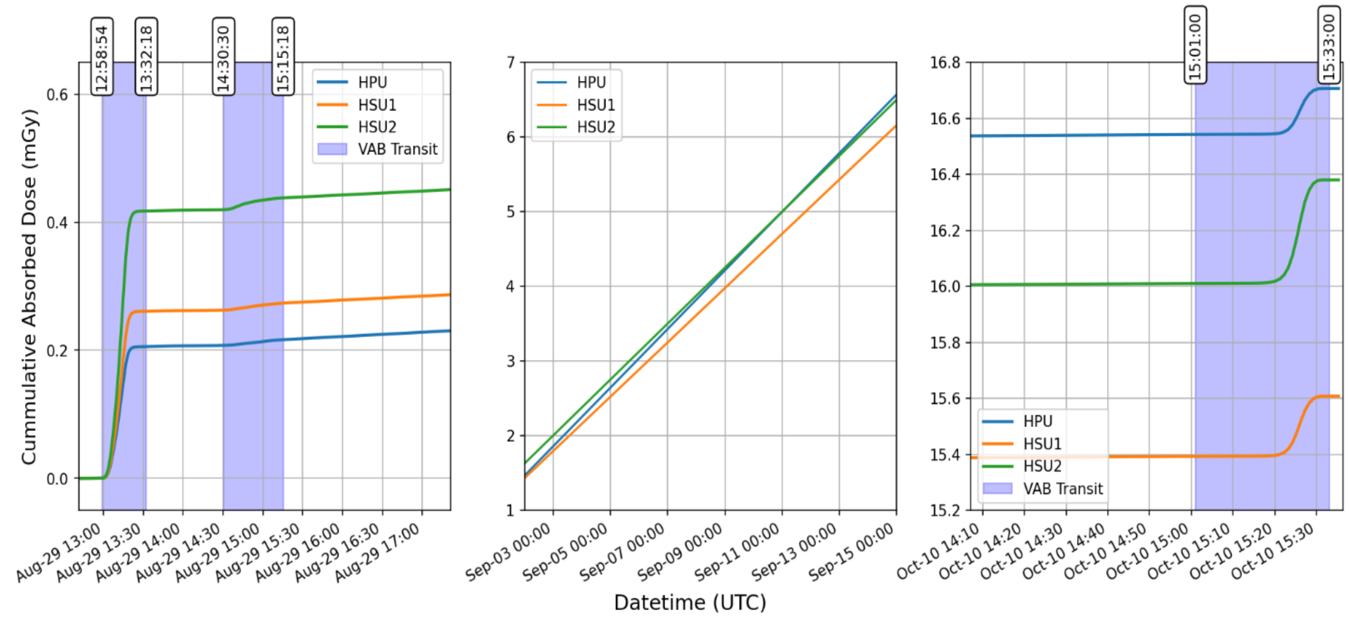
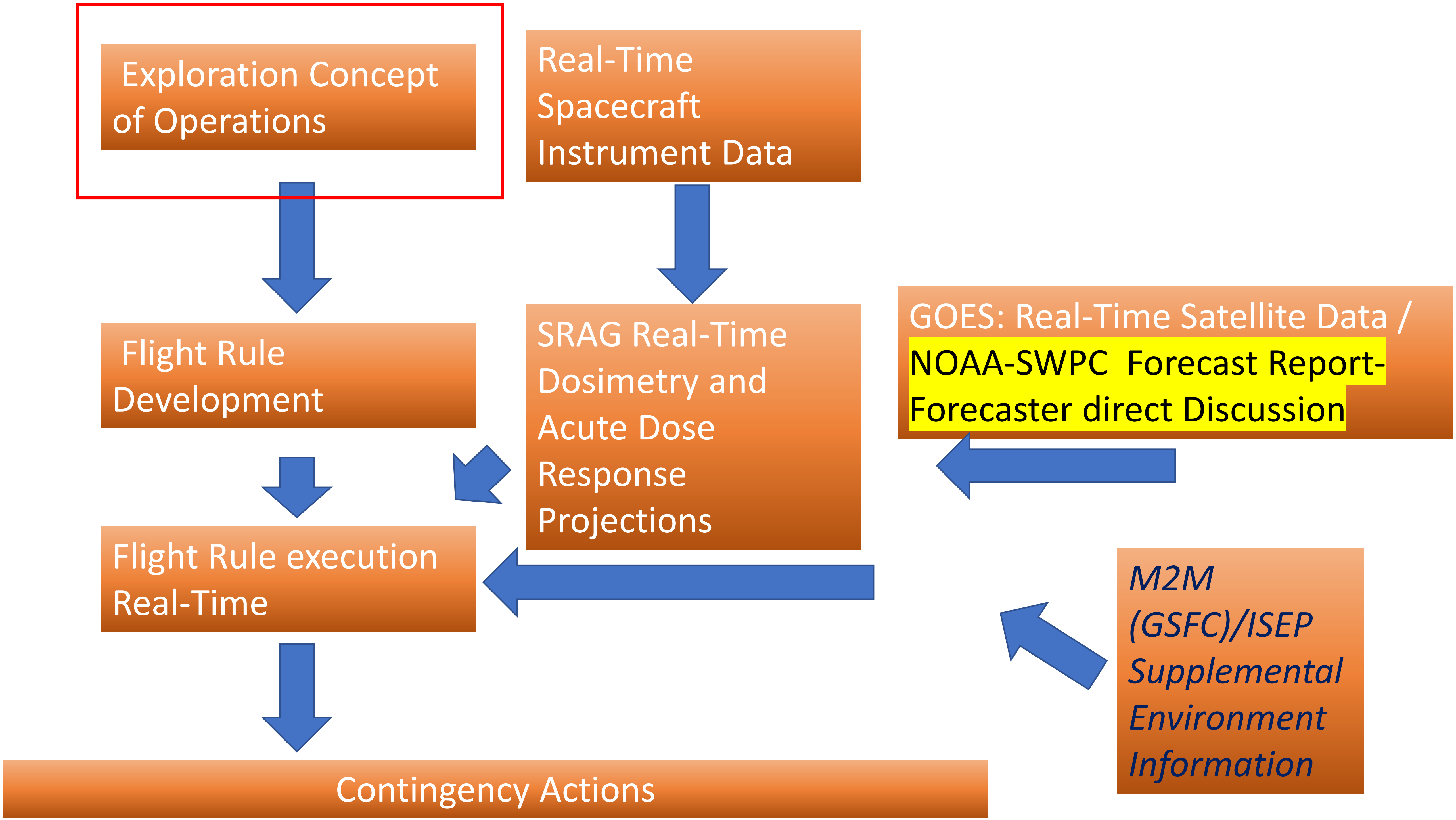
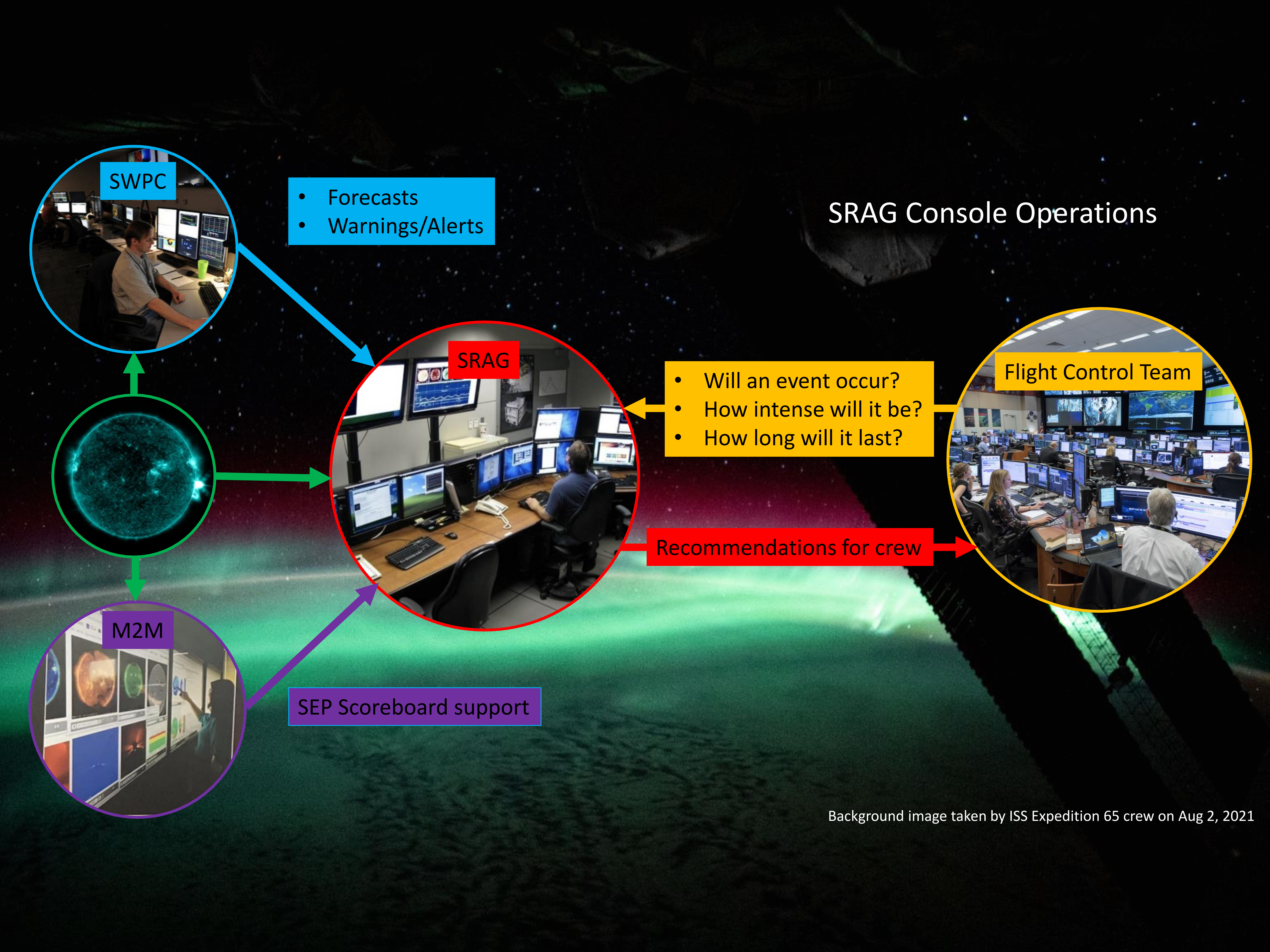
Matroshka AstroRad Radiation Experiment (MARE) Payload





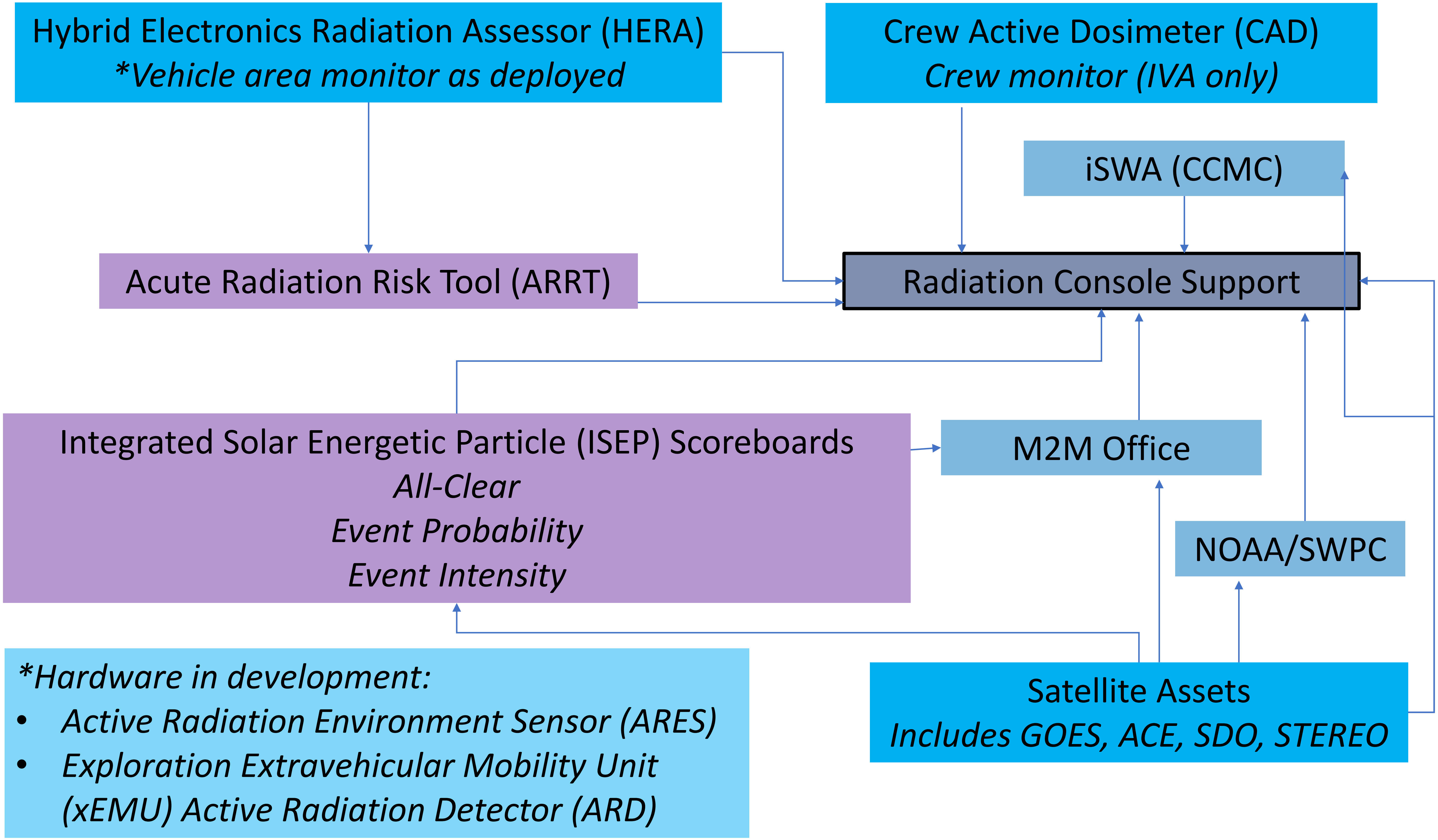
Operational Schema for Artemis Missions





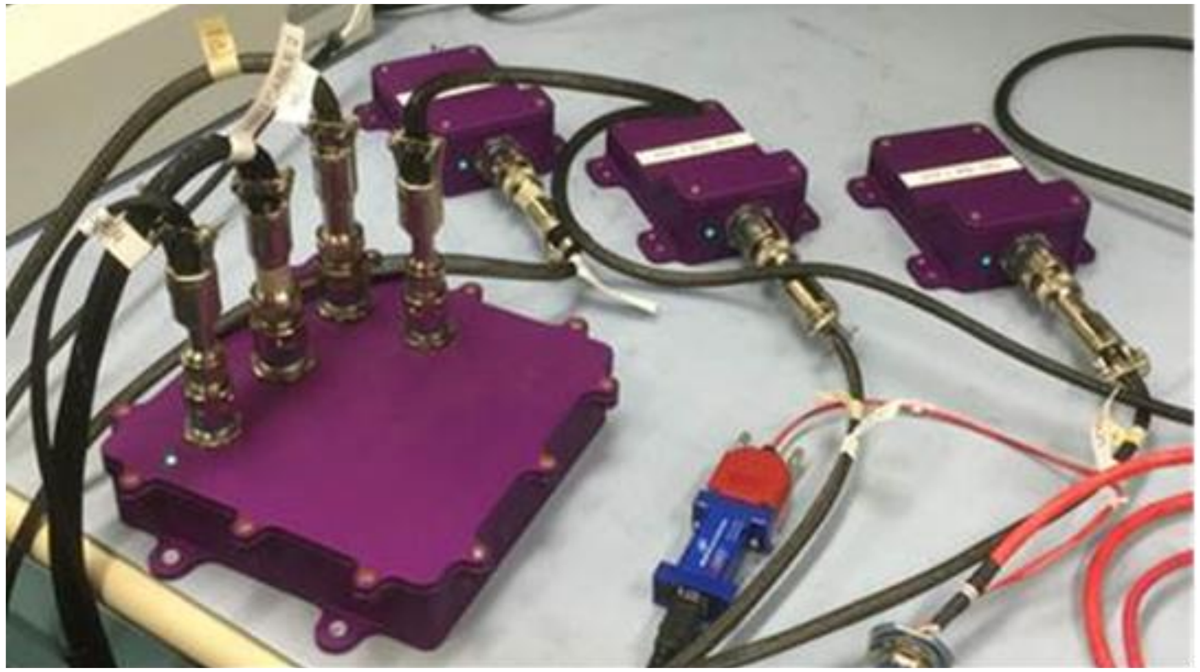
Background image taken by ISS Expedition 65 crew on Aug 2, 2021

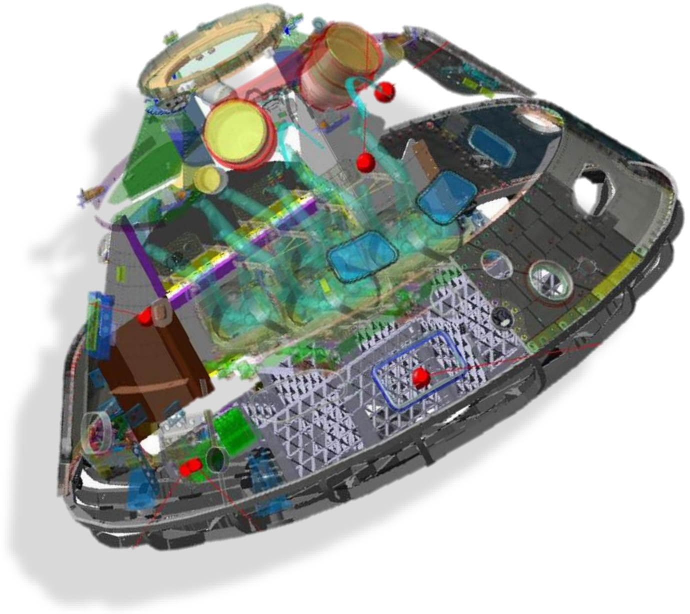
Artemis Operational Assets



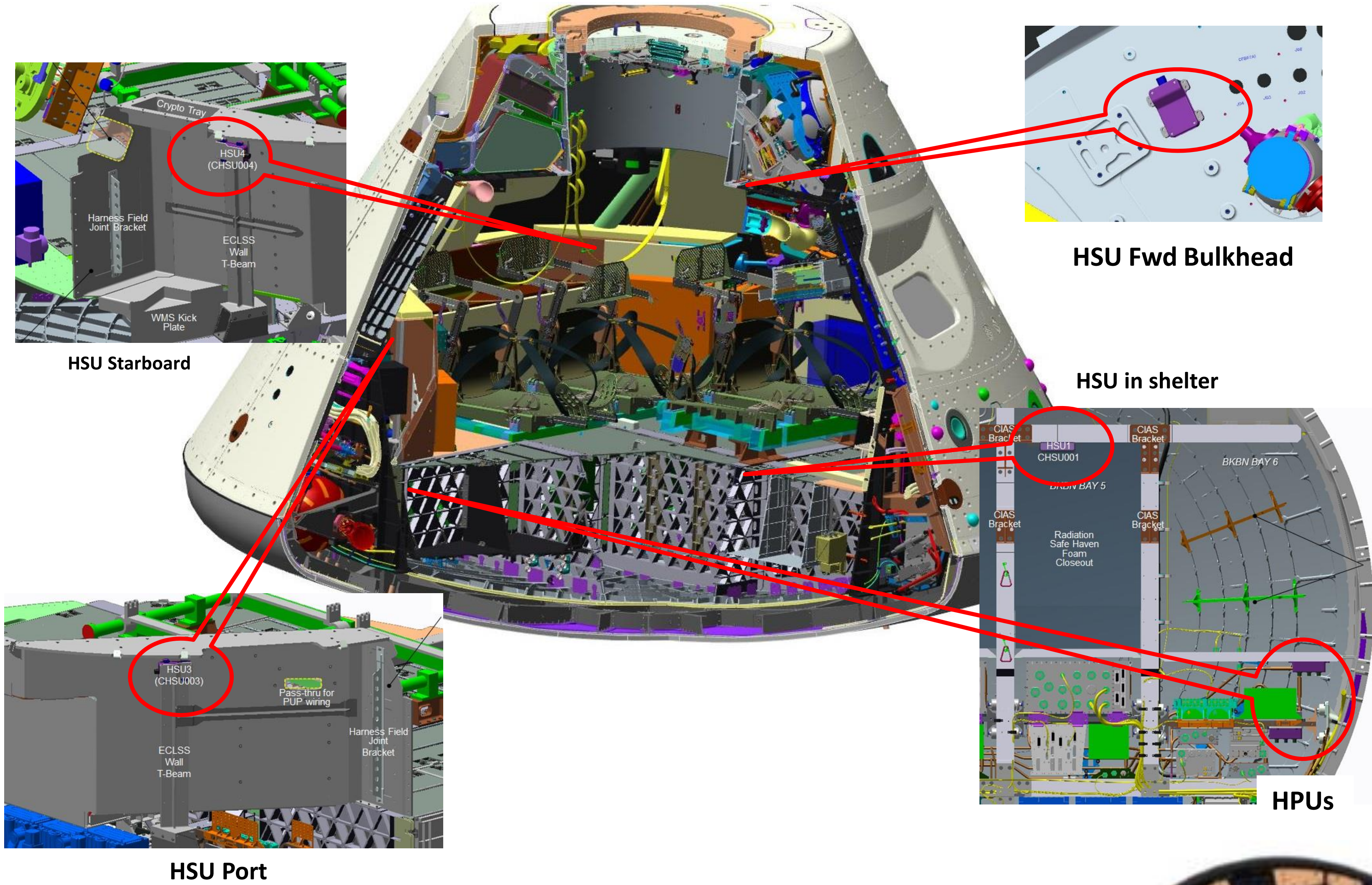
Hybrid Electronic Radiation Assessor (HERA)

- **The HERA Artemis 2+ Systems composed of two independent strings of power/processing units, and sensors. Each flight string is composed of one processing unit and 2 sensing units.**
- **MEL; Allocation 7.884 lbm, Actual 7.28 lbm**
- **Provides real-time radiation environment data to ground & on-board displays, alarming functions, and absorbed dose measurement & predictions. Provides in-flight binning of particle charge and energy. Stores/downlinks raw data for detailed analysis**
- **Designed and built by AES RadWorks team**
  - Funded by AES
- **Artemis 1 hw installed; Artemis 2 hw is awaiting installation; Artemis 3+ hw final buildup and delivery complete.**





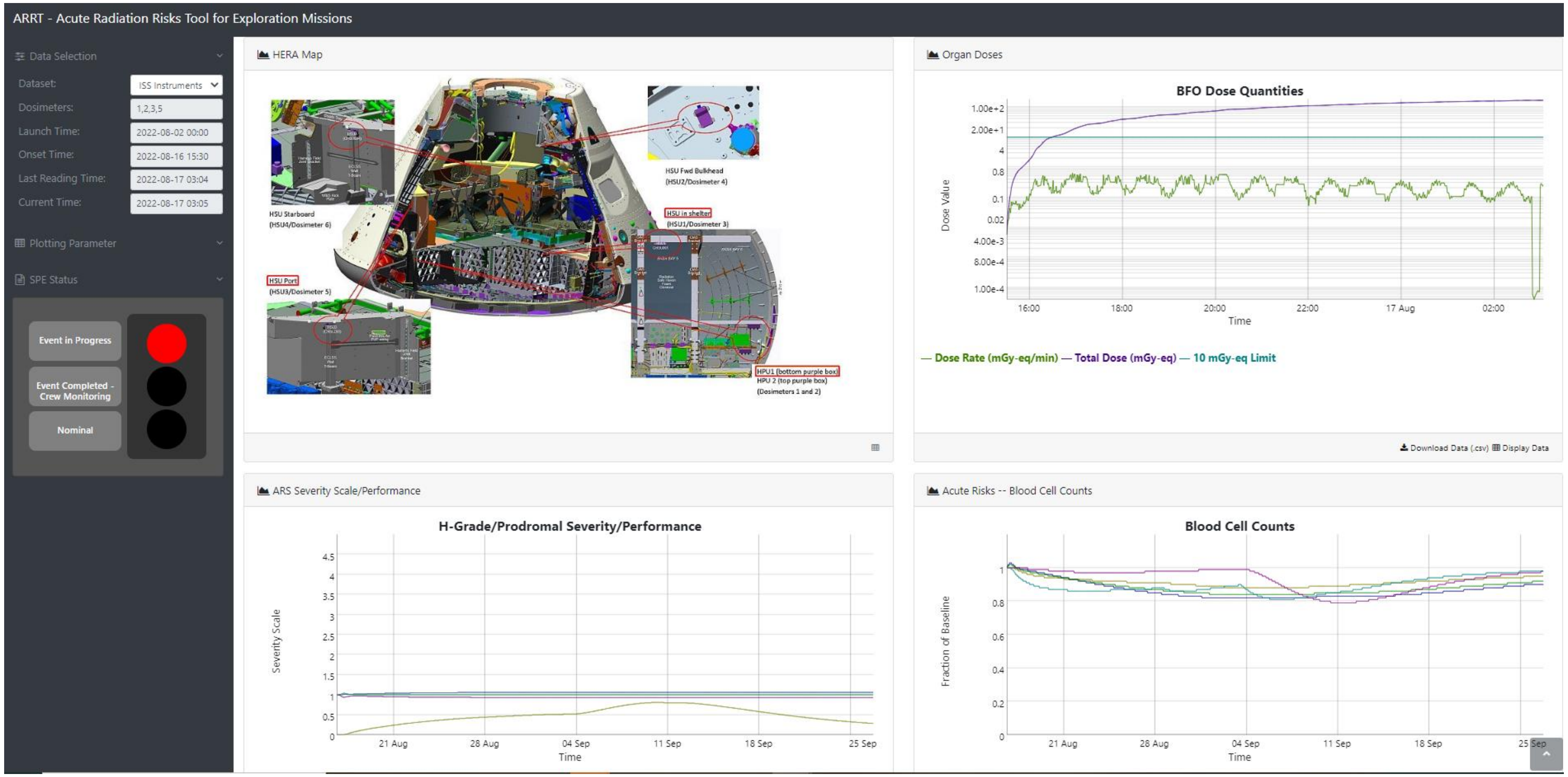
HERA Vehicle Locations



Storm Shelter

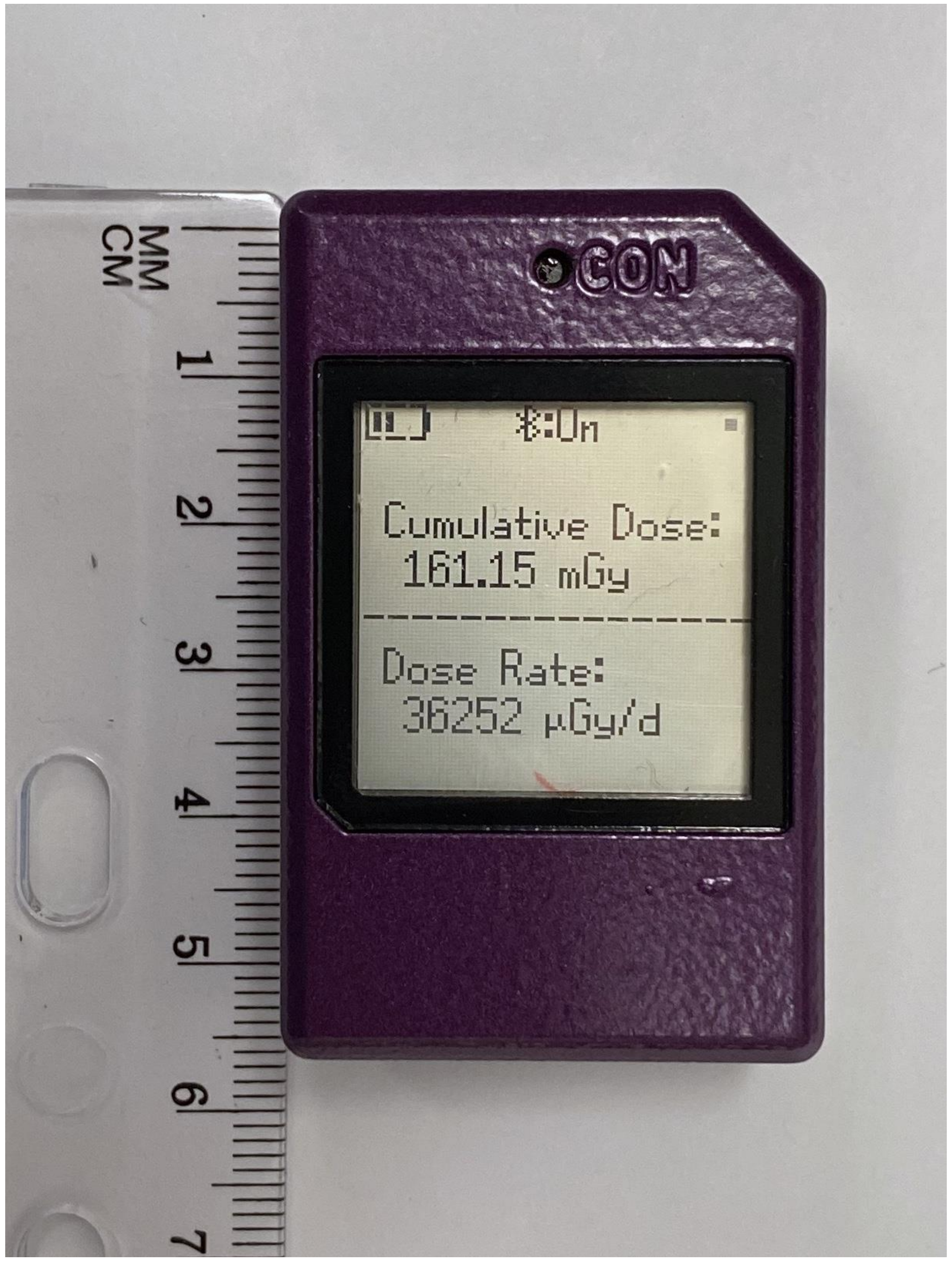
Acute Radiation Risk Tool (ARRT)

ARRT is a new console tool developed by SRAG for contingency event support based on vehicle instrument (dose) data



Crew Active Dosimeter (CAD)

- **Crew worn Direct Ion storage (DIS) low power, small size, rugged**
- **Meets the crew worn radiation monitoring requirements**



RadWorks

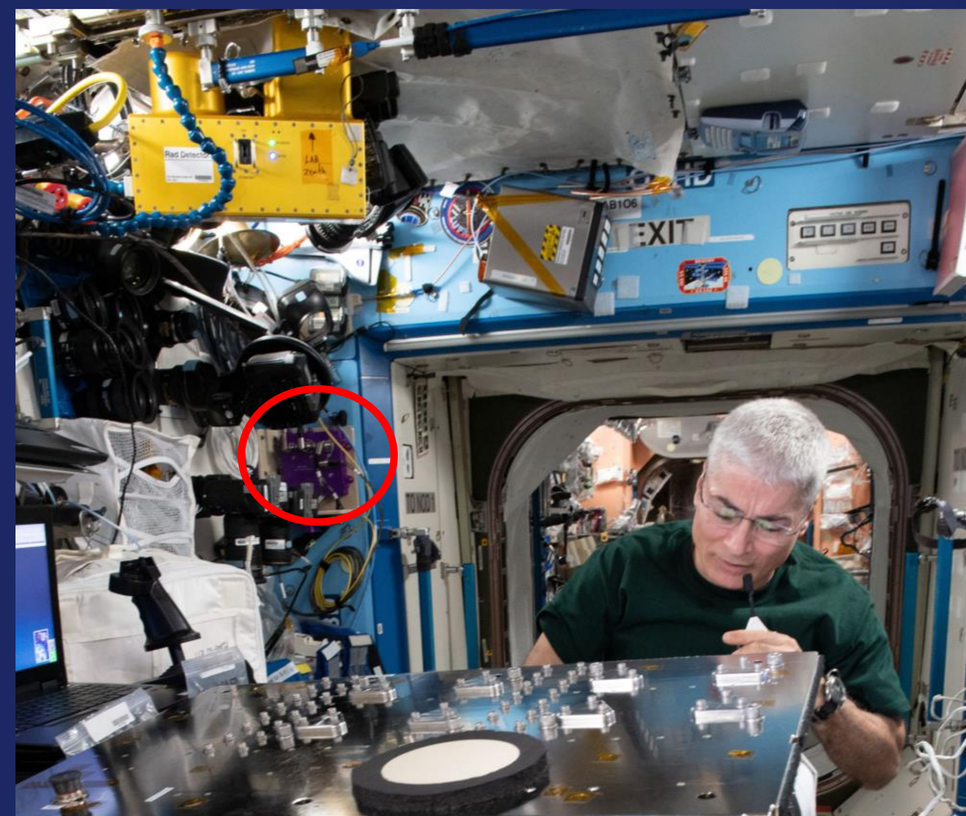
Project Overview

Why is this project important?

- Space radiation environments for Lunar and Mars missions must be characterized to determine astronaut crew exposures; information that is vital to influence vehicle design and mission planning. RadWorks builds on detection, shielding, and modeling capabilities developed over the past decade to provide solutions that inform the design and operations of all aspects of NASA exploration spaceflight missions.

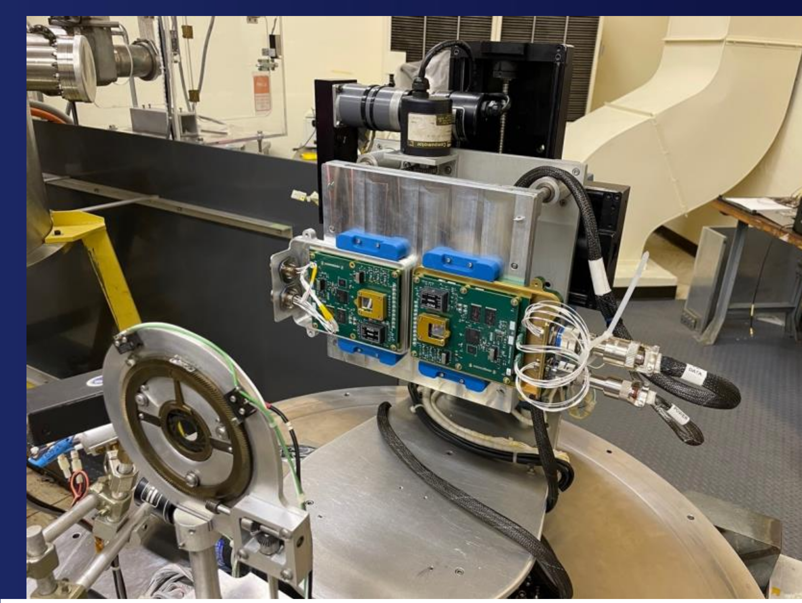
Objectives

- Advance technologies and develop hardware that supports NASA's Space Exploration efforts to manage and minimize crew radiation risks for Health and Human Performance.



A-HoSS on ISS

ARES Qual Unit Assembly



ARES BNL/Tandem Test Config for Calibration
L. ARES EDU R. ARES Qual Unit

Current Activities

- Radiation detectors:
  - Development of Timepix-based sensors for operational monitoring on ISS, MPCV, Gateway, and Human Lander Systems
  - Demonstration of low power, low mass neutron spectrometers
- Radiation exposure modeling & assessment tools:
  - Development and validation of improved space environment and physics models
- Radiation protection technologies and shielding solutions:
  - Demonstration of active shield concept with validation of scaling laws
  - Demonstrate wearable protection concepts

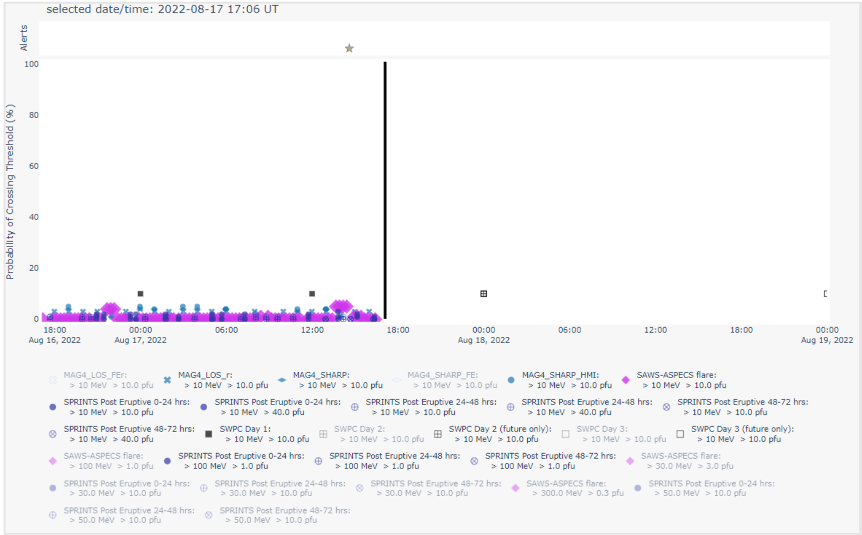
HZETRN Updates

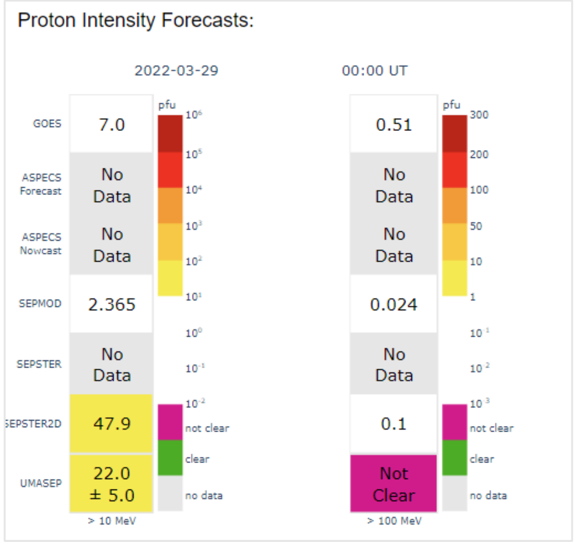
Radiation Transport/Analysis Tool Updates for Assessment of GCR and SPE Shielding

- HZETRN2020 completed – Completed FY21
  - HZETRN is NASA's space radiation transport code
  - It is used to calculate the transport of GCR and SPE environments through spacecraft shielding materials
  - It has been and/or will be used in the assessment of shielding for all Artemis human rated spacecraft: Orion, Gateway, HLS, Mars Transport Vehicle, surface habitats, and rovers
  - HZETRN2020 improves the accuracy of these calculations through the inclusion of multiple physics updates (heavy ion production models, neutron and light ion production models, improved coupling of charged ion and pion transport) and the enabling of 3D transport calculations
  - Validation with ISS and MSLRAD measurements showed good agreement (within the measurement uncertainty in most high latitude or free space regions)
- HZETRN2020 incorporated into LaRC and JSC human exposure calculation scripts for free space and surface missions – Completed FY21
  - Recently used for Gateway IAC 7 and 8 assessments
  - Currently being used for NASA assessment of HLS
- HZETRN2020 incorporated into the OLTARIS (On-Line Tools for the Assessment of Radiation In Space) website – Completed FY22
  - OLTARIS makes NASA's space radiation assessment tools (environment models, transport code, human body models, vehicle geometry handling scripts, and human risk models) available to NASA partners and non-expert NASA users
  - OLTARIS is currently being used by SpaceX for HLS SPE protection assessment
- OLTARIS updates to facilitate SpaceX geometry formats – completed FY22
- Improved pion production physics modeling for more accurate thick shield transport calculations – To be completed FY23
- OLTARIS updates to facilitate simple geometry surface habitat trade analyses – To be completed FY23
- OLTARIS updates to make it easier for novice users to perform spacecraft assessments – To be completed FY23

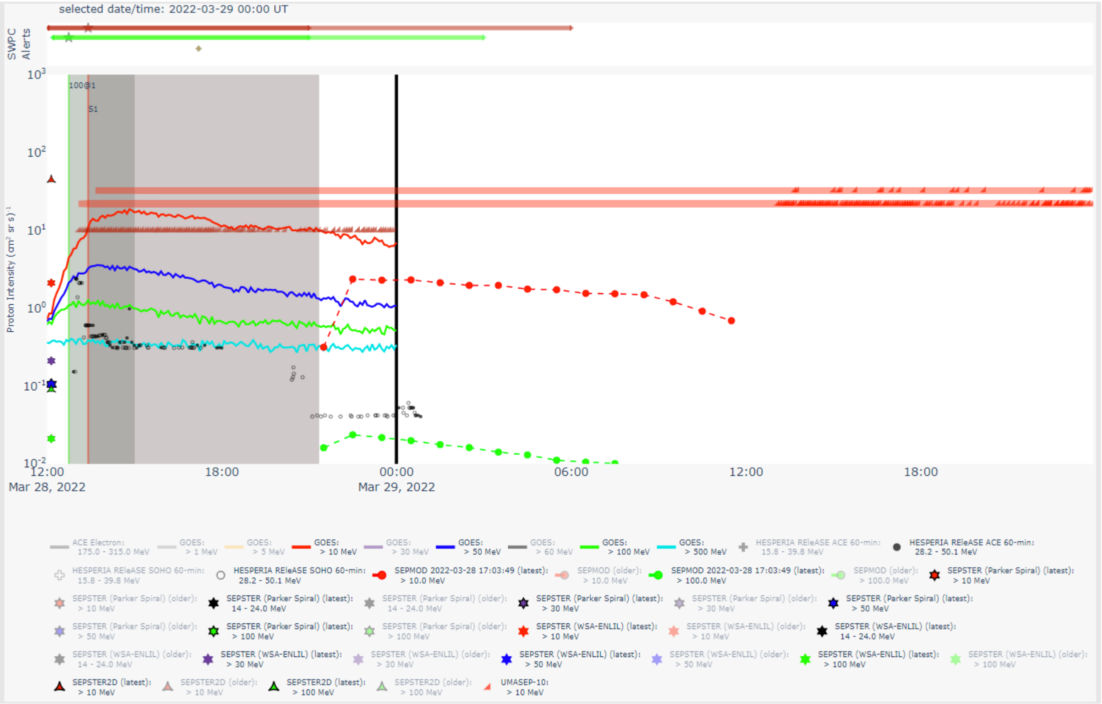
ISEP Scoreboards

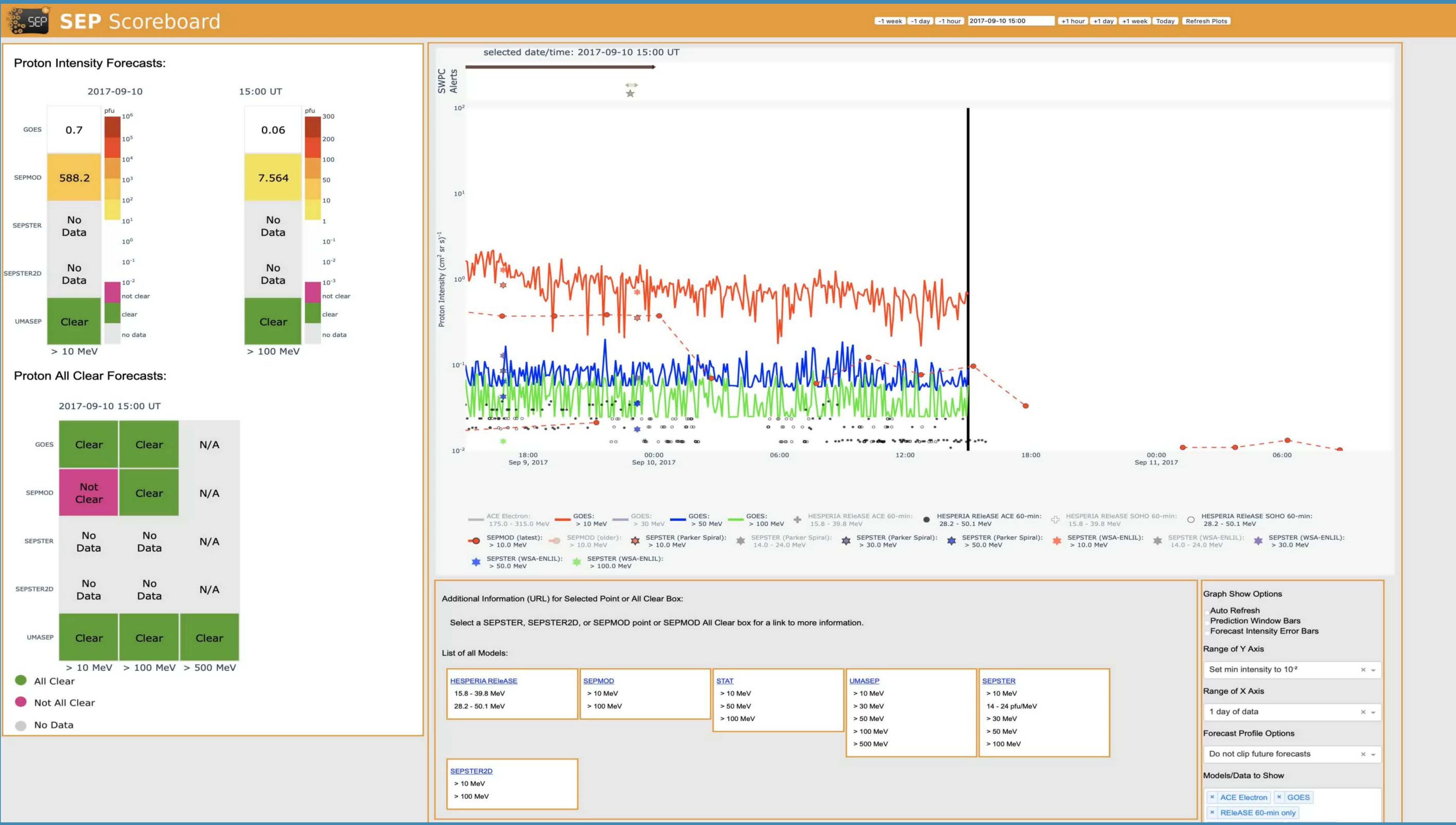
- Artemis-I Capabilities
  - Probability Scoreboard
  - Intensity Scoreboard/Peak Flux Heat Map
  - All-Clear Scoreboard
- Scoreboards in use for ISS during SC 25
  - Daily communication with M2M
  - Internal model documentation and review
  - Operators familiar with model strengths and weaknesses





	GOES	SWPC Day 1	MAG4_SHARP_HMI	MAG4_SHARP	MAG4_LOS_r	SEPMOD	SEPSTER	SEPSTER2D	UMASEP
> 10 MeV	Clear	Not Clear	Not Clear	Not Clear	Not Clear	Clear	Clear	Not Clear	Clear
> 100 MeV	Clear	No Data	No Data	No Data	No Data	Clear	Clear	Clear	Clear
> 500 MeV	Clear	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Clear





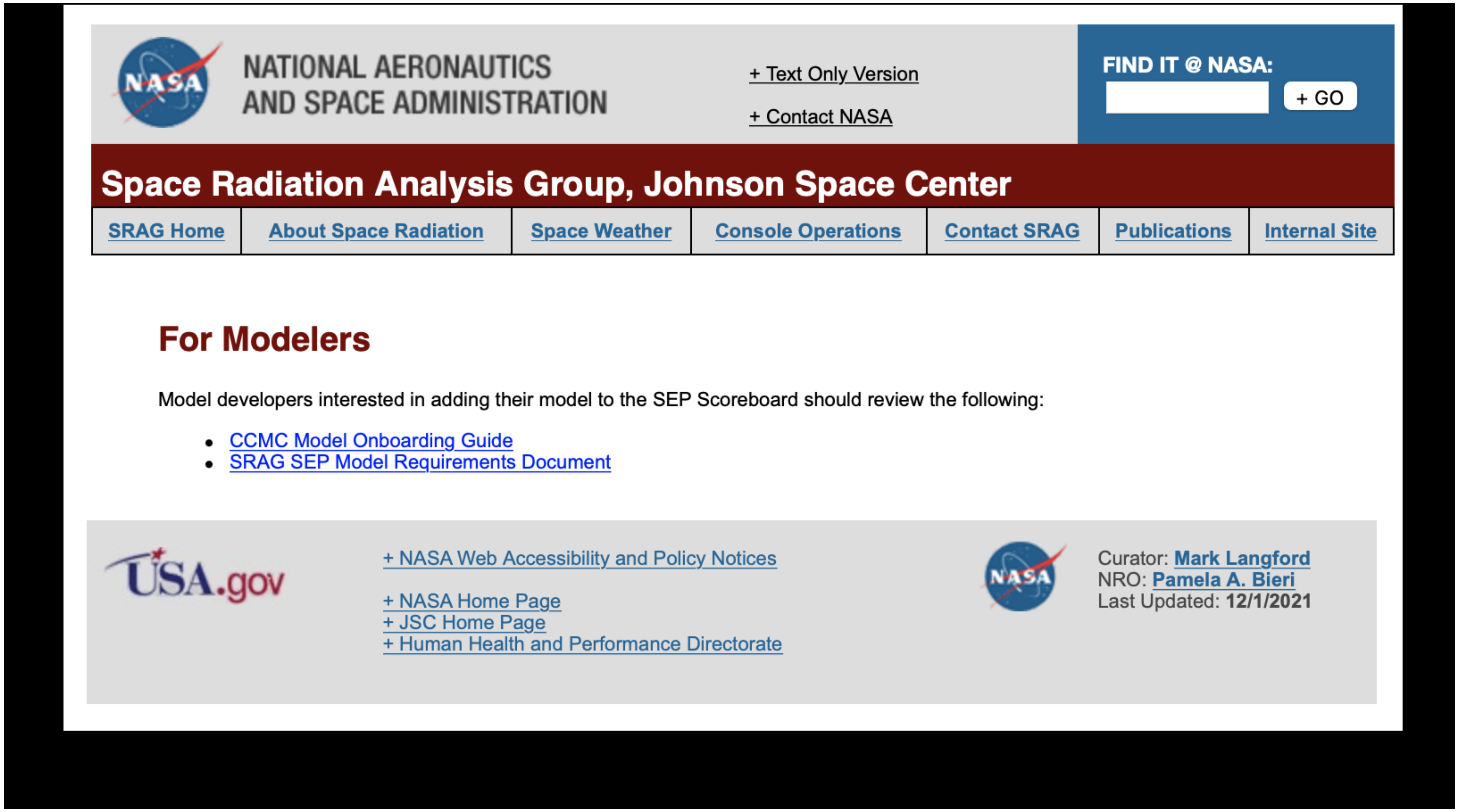
CCMC versions:

https://sep.ccmc.gsfc.nasa.gov/probability/

https://sep.ccmc.gsfc.nasa.gov/intensity/

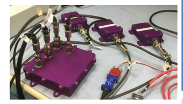
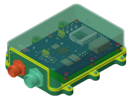
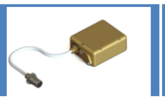
https://sep.ccmc.gsfc.nasa.gov/allclear/

SEP Model Reqs – SRAG perspective



https://srag.jsc.nasa.gov/SpaceWeather/Modelers.cfm

Instrument Suite for Crewed Artemis Missions

Function	HERA 	CAD 	ARES 	ARD 	Neutron Detector*
Type of measurement/ what is measured	• Charged Particle Detector • Area monitoring of flux/species and dose	• Crew member dose rate/total dose	• Charged Particle Detector • Area monitoring of flux/species and dose	• Crew member dose rate/total dose	• Neutron flux
Proposed mission	• Orion	• Personal dosimeter worn by crew at all times (except for EVA, because of battery & lack of vacuum capability) • Manifested by Orion	• Gateway, Lander • (HERA heritage hw)	• EVA, integrated with xEMU	• Vehicles with crew, including HALO, HLS, Orion
Use	• Real time monitoring • On board alerting	• Real-time dose at crew • Post mission crew risk assessment, re-flight determination	• Real time monitoring • On board alerting	• Real time dose at crew • On board alerting • Post mission crew risk assessment	• Post mission Crew risk modeling, re-flight determination
Mounting	• Hard mounted	• Crew worn	• Soft stow, Velcro mount	• TMG pocket (installed pre-launch)	• Soft stow, Velcro mount
If we don't collect data?	• No area monitoring, no C&W for crew	• No data for risk assessment	• No area monitoring, no C&W for crew	• No C&W for crew, no data for risk assessment	• No data for crew risk modeling
Power	• 120V	• Battery	• PnP/28V	• 12V	• PnP/28V
Comm	• RS422	• Bluetooth	• Ethernet	• RS485	• USB or RS422
Mass	• ~3kg	• 35g	• <2kg	• 430g	• 4.25 kg
Dimensions/ volume	• HPU: 19.3 cm x 17.5 cm x 4.6 cm • HSU (2each): 13.5 cm x 10.7 x 5.3 cm	• 5.7 x 3.4 x 2.6 cm (51cm3)	• 9.9 cm x 17.8 cm x 4.6 cm (811 cm3)	• 7 cm x 6 cm x 3 cm	• 24.8 cm x 20.3 cm x 13.3 cm (based on current preliminary designs)

Radiation Monitoring Concept of Operations – Logistic Module (LM) example Single Monitoring Point Approach

- **GW Requirements are derived from parent requirements in NASA Standard 3001, V2 in order to adequately protect and inform both the crew and ground regarding the radiation environment in spacecraft. Measurements and alerting shall be conducted where the crew is generally located to provide adequate situational awareness and to avoid high rate exposure areas.**

- **The ability to measure in the high occupancy/traffic modules (HALO, iHab) of GW is considered by SRAG to be aligned with the NASA standard intent.**

  <u>Environment trending and Alerting are provided by ARES using real time, low latency data</u>

- **Individual monitoring (CAD) is required to be worn continuously to capture crew specific exposure, this is for normal and elevated exposure conditions like an SPE. Although CAD does not provide alarm/alert, it is directly readable by the crew member to evaluate rapid changes (over 10 min for example) in exposure during SPE.**

  <u>In/Post flight crew exposure/risk assessment is completed using captured/stored summary data from both CAD and ARES</u>

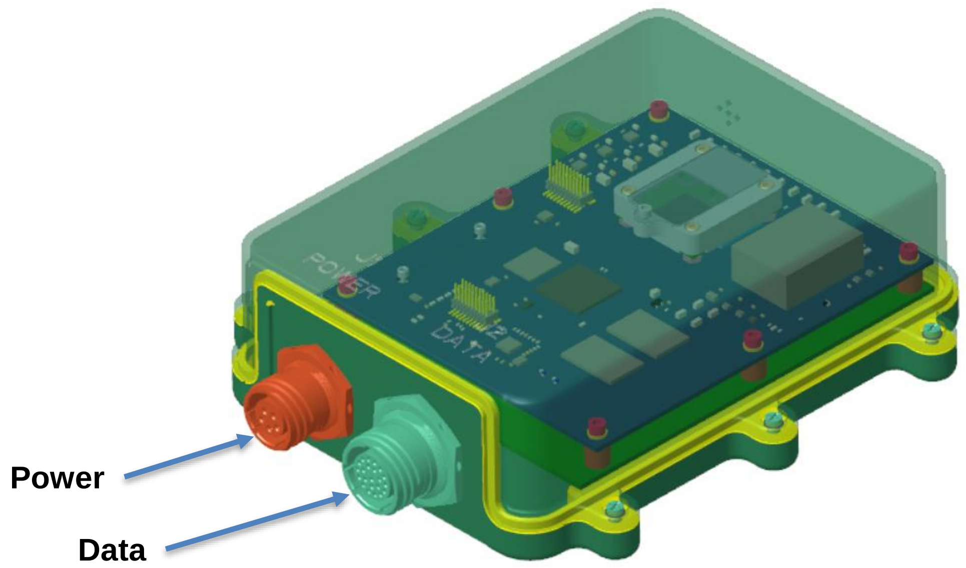
- **Crew will be trained to utilize the local display on CAD to track their in-mission exposures.**

- **During large SPEs, SRAG will request periodic readings to be made by the crew and called to the ground. Ground Console will be able to utilize these CAD measurements from crew members that spent time inside the LM vs. inside the HALO/iHAB to determine the increased exposure (if any) of the crew member while in the LM.**
  - **This exposure delta (if any) can then be used to anchor models to develop total exposure while in the LM for those short duration WMS excursion**
  - **We have confirmed by ground testing that the CAD display successfully tracked/distinguished changes in exposure over anticipated ranges we will see during SPEs (e.g., ~20-80 μGy/min) within multiple short duration exposures similar to WMS usage cases in GW**
  - **Differences < 1% of the short term exposure limit of 250 mGy-Eq**

- **WMS use is an essential function that may have to occur during an SPE – SRAG will inform FCT on suggested times for LM entry during SPEs**
  - **SRAG will inform FCT of potential differences that may occur for WMS usage if a shelter recommendation is underway. Large exposures are not expected for short term excursions to WMS**
  - **NOTE – this paradigm is already accepted/planned for Orion - crew must exit shelter to utilize toilet in area that is NOT monitored directly with HERA**

Active Radiation Environment Sensor (ARES) Overview

- Description of Sensor: Uses an active radiation sensing chip that incorporates currently-developed technology used in ISS, Orion, and CLPS mission radiation monitoring hardware. Its small profile, low mass, and low power consumption makes this an attractive solution for radiation sensing and detailed radiation field sampling capability on any vehicle.
- Core board capabilities are listed in the Technical Specification table →
- Housing and interface:
  - Velcro mounting with separate power and data interfaces
  - Qualified vehicle-independent design. Certification completed at final assembly

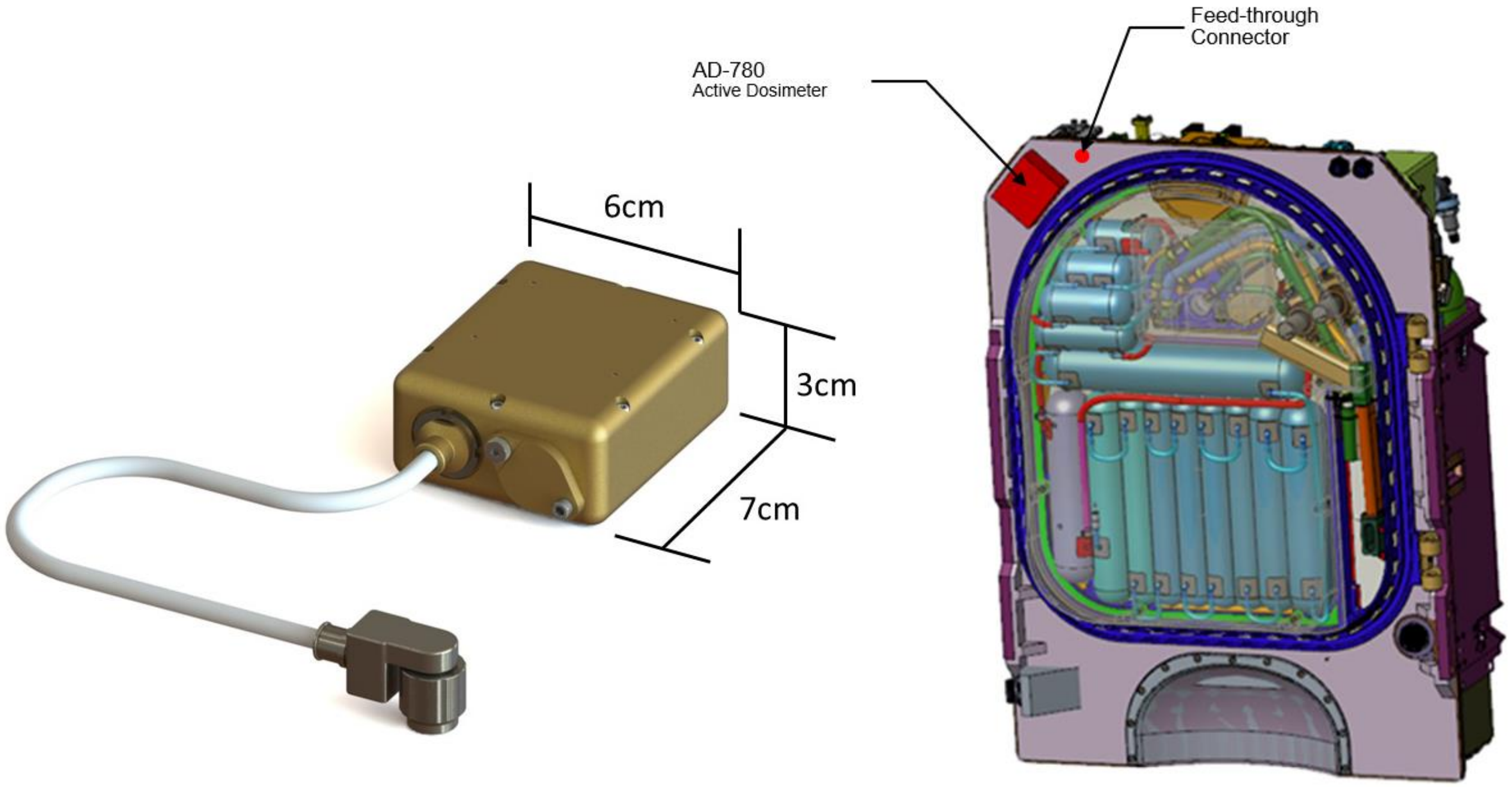


(Notional Design - For Reference Only)

Technical Parameters	
Instrument Type:	Silicon Radiation Sensor
Data Product:	LET Spectrum, dose rate, cumulative dose
Expected Flight Unit Mass:	1.6 kg (including housing)
Operating Temperature Range:	-24 to +61 °C
Non-operating (Survival) Temp Range:	-35 to +72 °C
Communication Interface:	RJ45 CAT 5E/6A MIL-DTL-38999 Connector / 1000BaseT Std Gigabit Ethernet
Data Transmission Rate:	Adjustable (2 msg./min – 2 msg./hr) - Science/Status: 1.5 kB/min – 1.5 kB/hr - Data Downlink: 510 kB/min (as req.)
Commanding:	Only Time Command required for nom. op. - Contingency commands: <30 B/Cmd - All current commands: <50 Bytes
Power Consumption:	3.6 Watts
Input Voltage:	28 VDC
Electrical Interface:	MIL-DTL-38999 Series III Connector
Housing:	Anodized Al-6061
Physical Volume:	7.36" x 5.70" x 2.15" (NTE 100 in.^{3})
Mass:	NTE 2.01 kg (4.4 lbm)
Launch, Acoustic, & Shock Load Limits:	Legacy designs surviving loads: - 6.8 grms Vibe (soft-stowed) - TBD shock (Velcro attachment, base design)
Radiation Sensitivity (SEU):	TBD

Active Radiation Dosimeter (ARD)

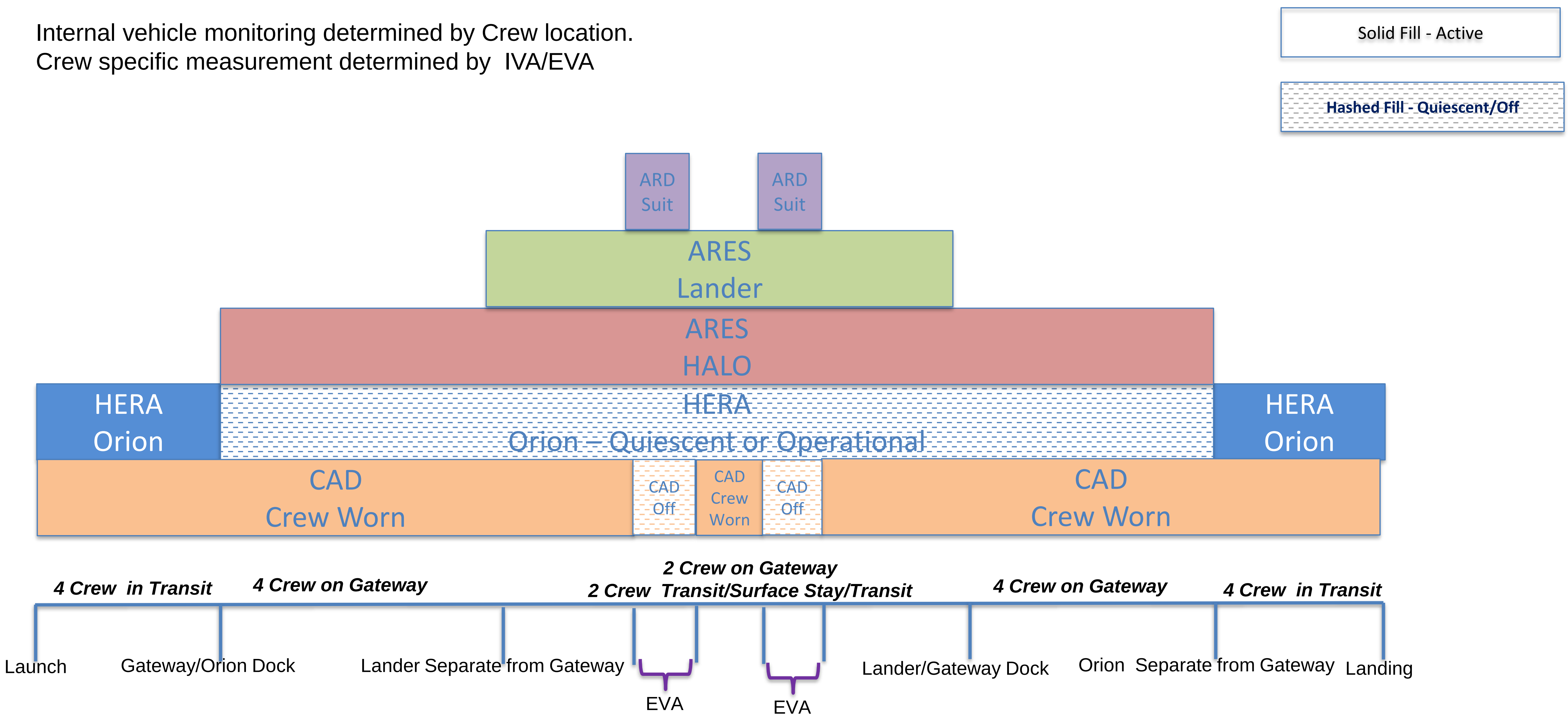
- Provides radiation detection, monitoring, and threshold alerts for the crew during extra-vehicular activity
- Integrated into the Exploration Extra-Vehicular Mobility Unit (xEMU) design
- Located in Thermal Micrometeorite Garment (TMG) pouch (shown as red box)
- Just completed SRR for device; planned delivery of 10 flight units in 2022
- Powered by the Exploration Primary Life Support System (xPLSS)
- Project managed by NASA/SD
- Designed and certified by The Aerospace Corporation
- Customer: EVA Program Office, funded by XX



Technical Parameters	
Instrument Type	**Silicon Radiation Sensor**
Data Product	**Dose Rate, Total Dose**
Housing	**Anodized Aluminum**
Mass	**430 g**
Dimensions	**6 cm x 3 cm x 7 cm**
Input Voltage	**12 Vdc**
Communication	**RS-485**
Telemetry	**RS-485 compliant with CTSD-ADV-1005**
Power Consumption	**250 mW @ 98% Duty Cycle 500 mW @ 2% Duty Cycle**
Electrical Interface	**Mighty Mouse 805 Series MIL-Spec Connector**
Operating Temperature	**-22 deg F to 104 deg F**
Non-Operating Temperature	**-40 deg F to 158 deg F**
Ground Test Interface	**USB 2.0**

Instrument Usage by Crewed Vehicle

Internal vehicle monitoring determined by Crew location.
Crew specific measurement determined by IVA/EVA



Artemis-I: Dry Run for (Crewed) Artemis-II

- NASA has improved capabilities for improving radiation exposure mitigation planning
- Some technologies (HERA, CAD, SEP Scoreboards) have been tested during ISS mission
  - Artemis-I is an opportunity to fully vet these technologies in a free-space environment with an uncrewed vehicle
- SRAG Operators will document successes and identify areas for improvement
- SRAG will implement lessons learned prior to crewed Art-II+ missions
- Science Payloads will contribute to total mission exposure assessment modeling