MARE: International Science aboard Orion EM-1 (Matroshka AstroRad Radiation Experiment)

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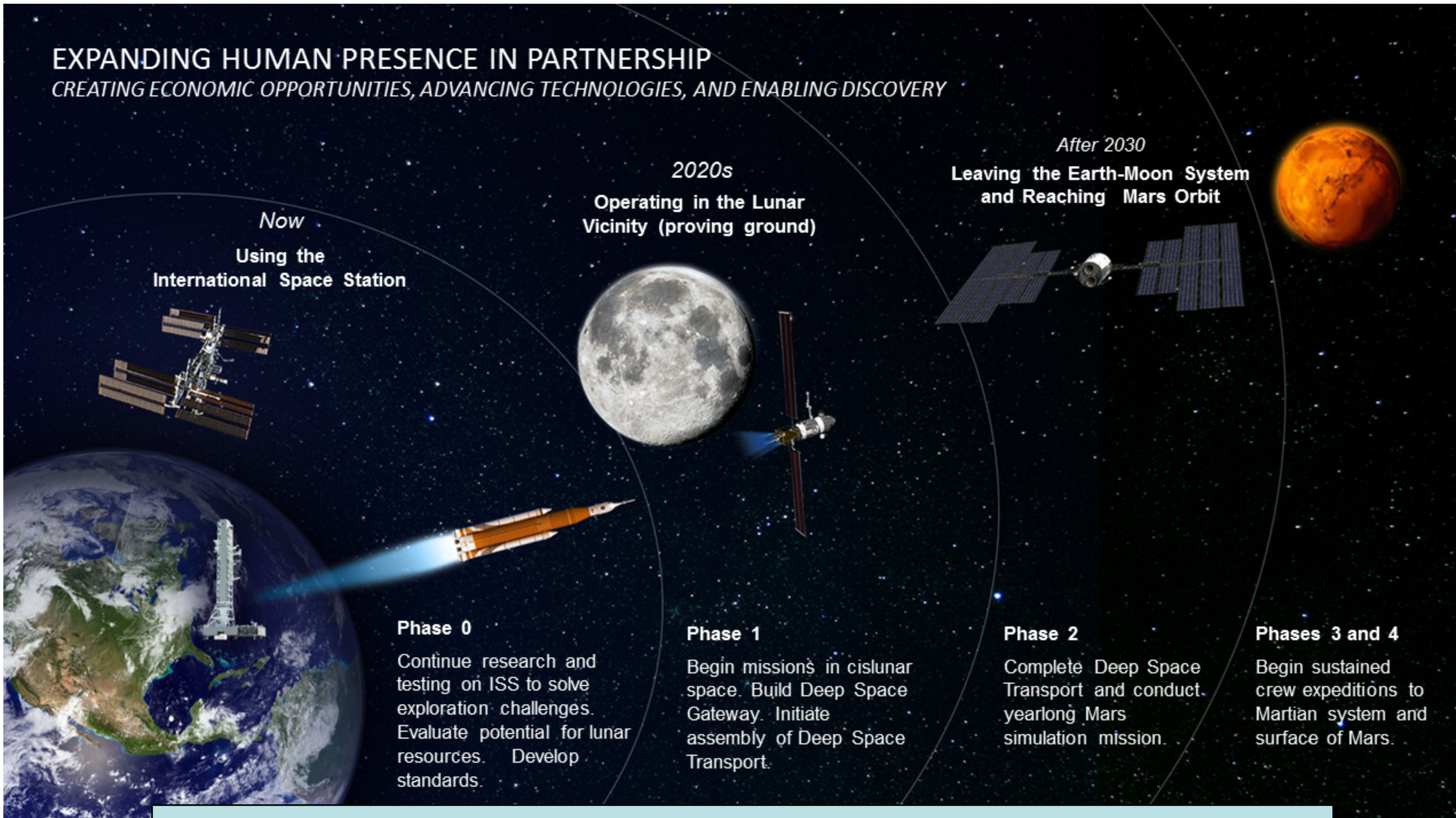
WRMISS 2017

Orion MPCV

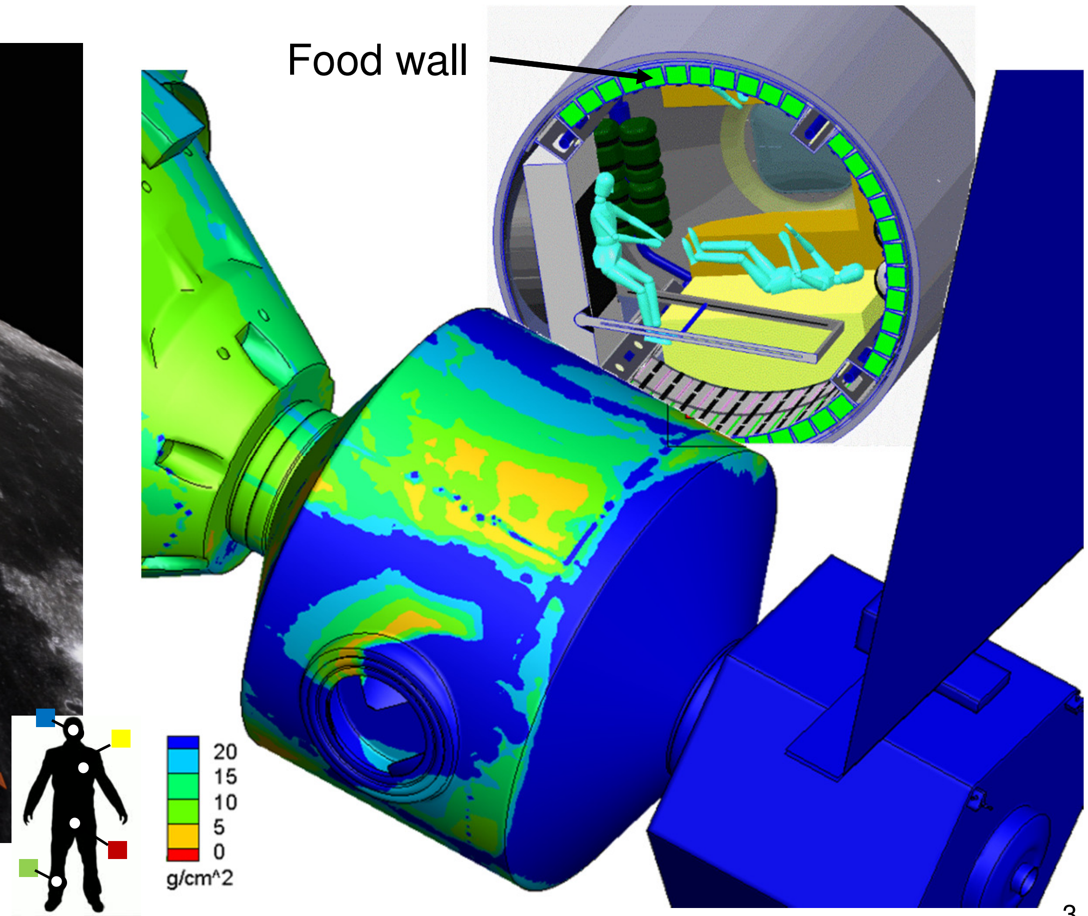
- **Orion is an Exploration Class spacecraft**
  - Crew radiation protection is a design requirement



Orion is a critical element leading to NASA's Mars missions

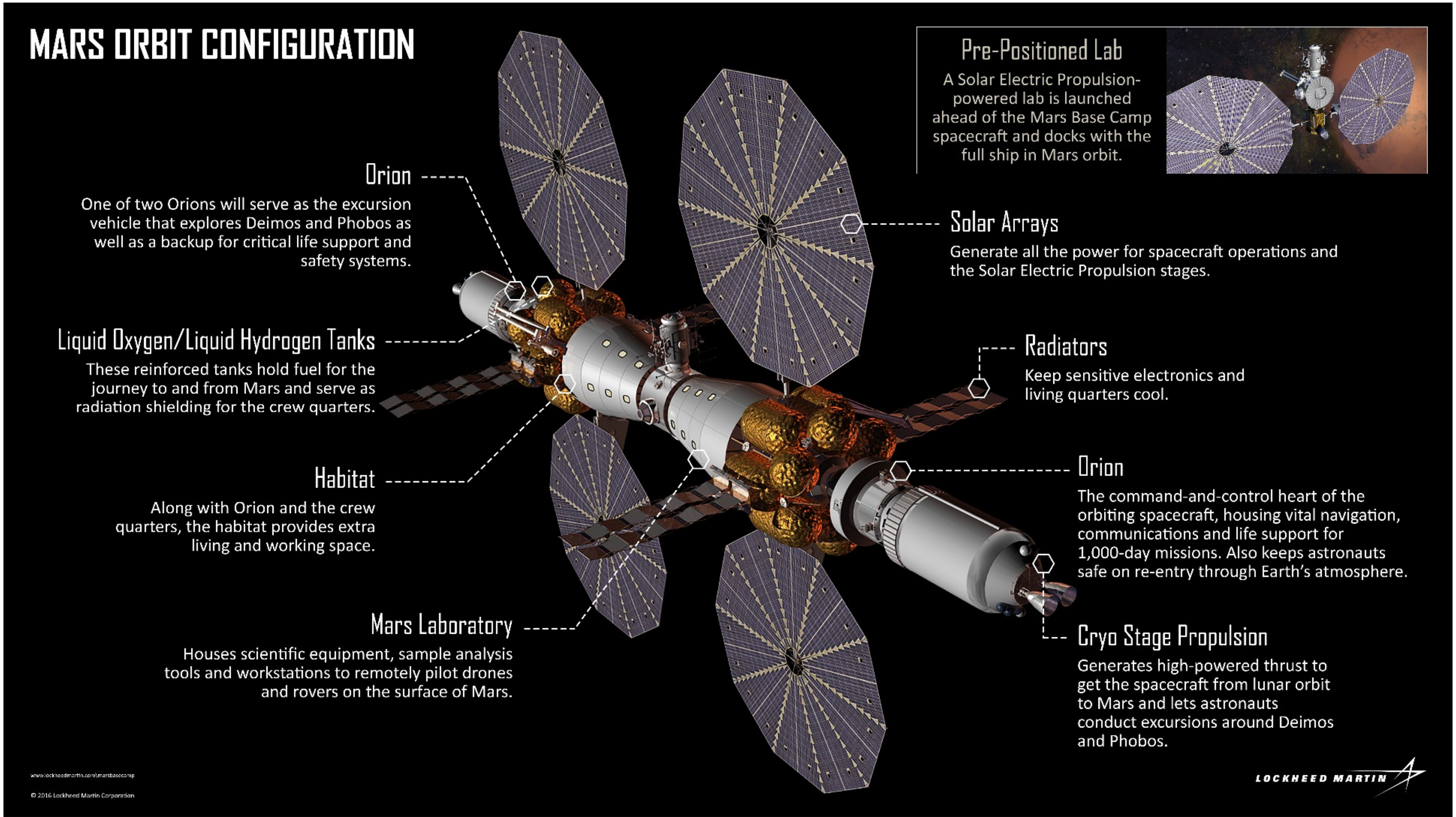
NASA DSG and NextSTEP

- **Deep Space Gateway: NASA proposed spaceport in cis-lunar space**
  - Allows testing new technologies in preparation for Mars class long duration missions
  - Lockheed Martin is developing a Habitat prototype as part of NextSTEP Phase 2
    - Design for radiation is performed from early design phases to maximize crew protection



Mars Base Camp

- **Lockheed Martin's vision for first NASA manned Mars Mission**
  - Mars-orbiting science laboratory in the 2028 time frame
  - Heavily leverages existing technologies: Orion, SLS, NextSTEP, SEP
  - Radiation protection is embedded in the architecture



Matroshka AstroRad Radiation Experiment

- **Next Orion test flight: Exploration Mission 1 (EM-1)**
  - Unmanned flight planned for 2019
  - First Orion flight beyond Earth orbit to cis-lunar space
  - Several science payloads
    - Cube-sats (e.g., BioSentinel) on SLS upper stage
    - Inside the Orion cabin
- **MARE is an EM-1 radiation science payload proposed by the Israel Space Agency (ISA) and the German Aerospace Center (DLR)**
- **Accepted by NASA and manifested for flight in May 2017**
- **Builds upon ISS Matroshka heritage**
  - DLR provides two Matroshka phantoms instrumented with radiation detectors
    - One Matroshka supported by ISA
  - One phantom fitted with the AstroRad PPE manufactured by StemRad & provided by ISA
  - MARE mechanical interface developed & produced by DLR
- **The MARE team includes Lockheed Martin personnel collocated with the Orion program for efficient payload integration**

Orion: Next Generation Platform for Space Science & Research

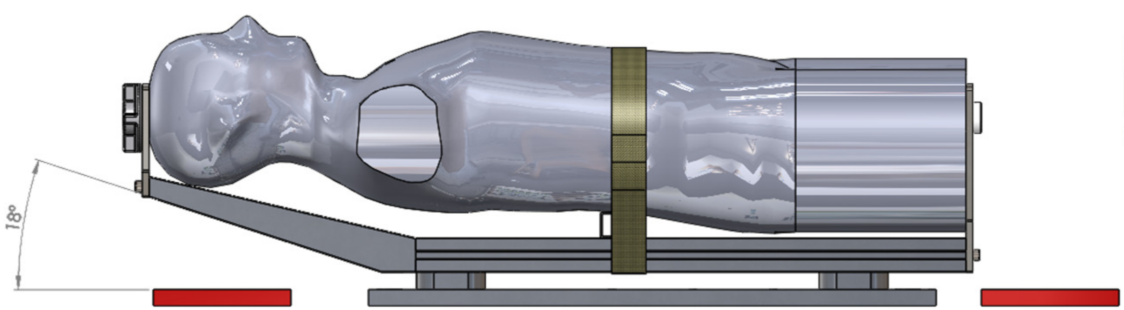
MARE

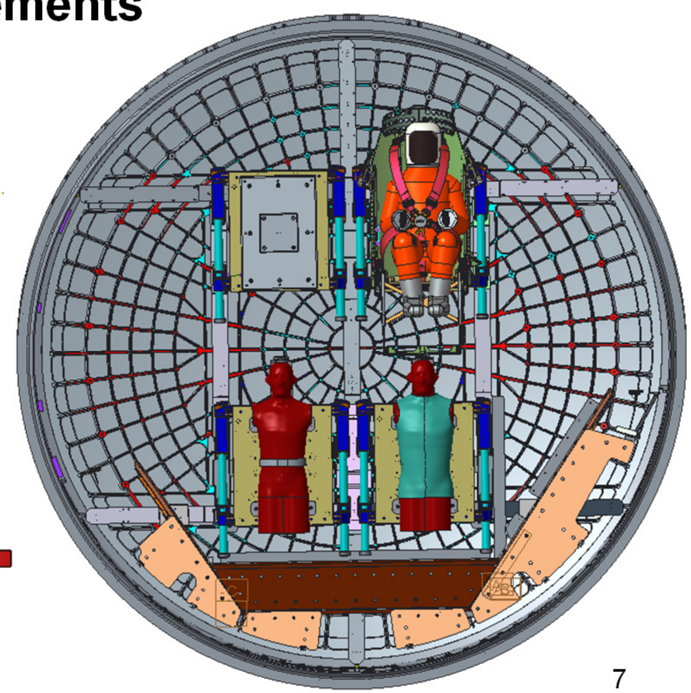
- **Experiment aims:**
  - To perform radiation measurements that help refine risk projections
    - Skin- and internal body organs dosimetry
    - During Van Allen belt transit & in cis-lunar space
    - Intravehicular environment specific to Orion
  - To validate the protection provided by AstroRad
  - To expand the ISS Matroshka international participation heritage
  - Trailblazer for science payloads on Orion
- **International participation opportunities**
  - DOSIS 3D community will provide passive sensors for dosimetry intercomparisons
  - Additional participation may be possible subject to MARE ground rules and vehicle integration constraints.

Orion: Next Generation Platform for Space Science & Research

MARE Ground Rules

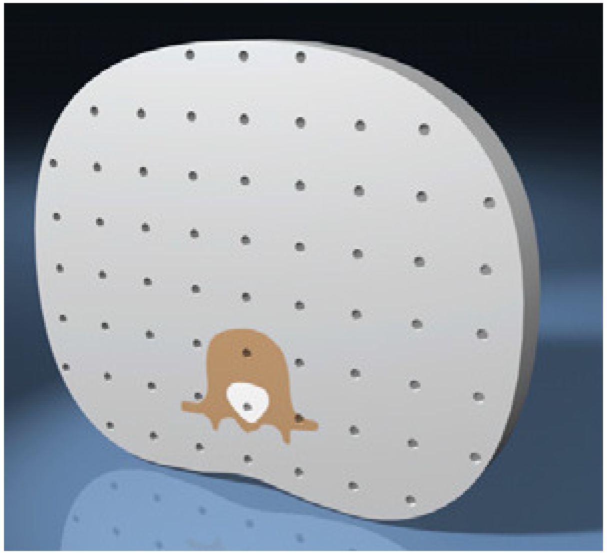
- **Phantoms will be installed inside the cabin at seat positions 3 and 4**
  - Phantom w/ AstroRad at position 3
  - Representative of the nominal crew radiation environment on upcoming missions
- **Payload is fully self-contained - no power and data interfaces from Orion**
  - Passive dosimeters: TLDs, OSLDs, PNTDs (CR-39)
  - Battery powered active detectors with integrated data processing and recording
- **Payload installation at L-15 days, post-flight removal at S+15 days (KSC)**
- **Payload must satisfy all vehicle safety requirements**
- **Mass and volume allocation**

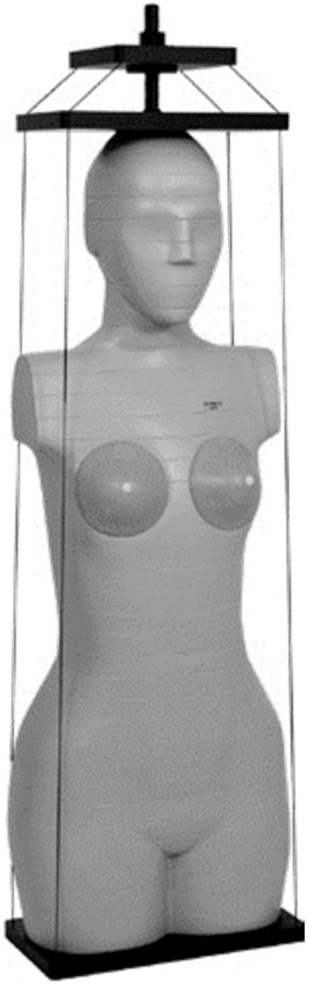




CIRS Radiation Phantom

- **Made of tissue-equivalent material & containing human skeleton**
  - Female Model
  - 38 slices: 95 cm (38 in) / 35 kg (75 lbs)
  - TLD holes in 3 cm grid over the phantom

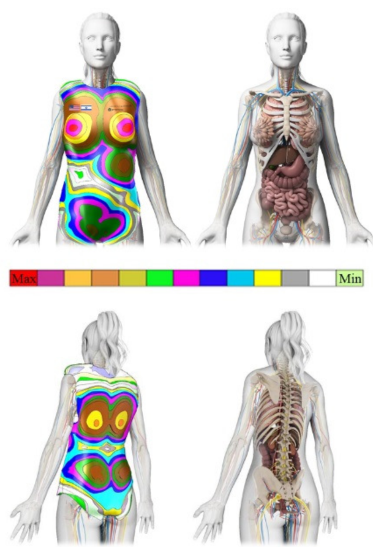




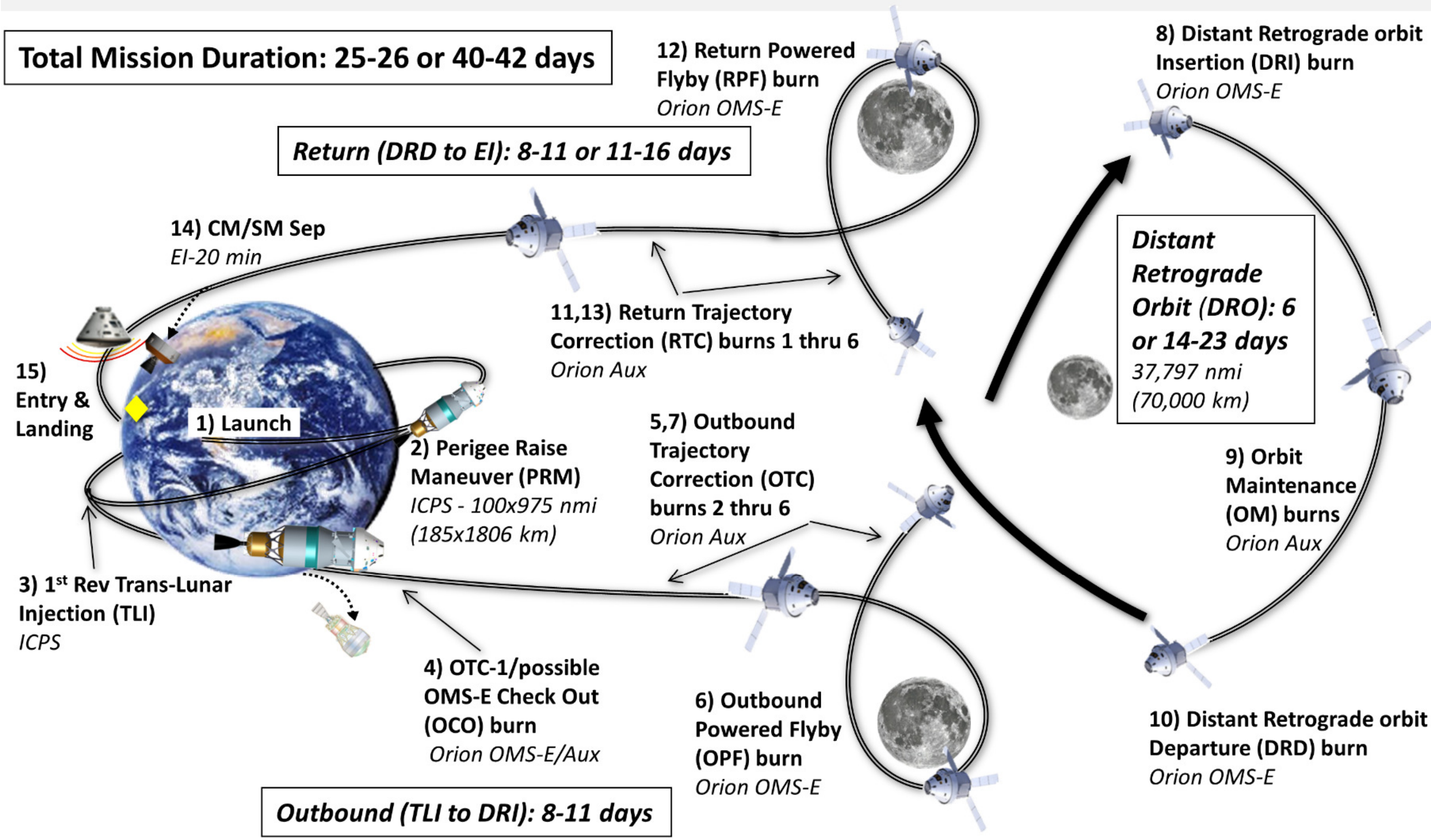
http://www.cirsinc.com/products/modality/33/atom-dosimetry-verification-phantoms

AstroRad Radiation Vest

- **Developed by international collaboration between StemRad Ltd and Lockheed Martin SSC Advanced Programs**
  - Grant funding by MATIMOP and Space Florida
- **Astronaut individually customizable personal protective equipment**
  - Designed using StemRad proprietary algorithms for selective shielding optimization focused on stem cell rich organs and tissues
  - The manufacturing process leverages StemRad ground radiation protection expertise



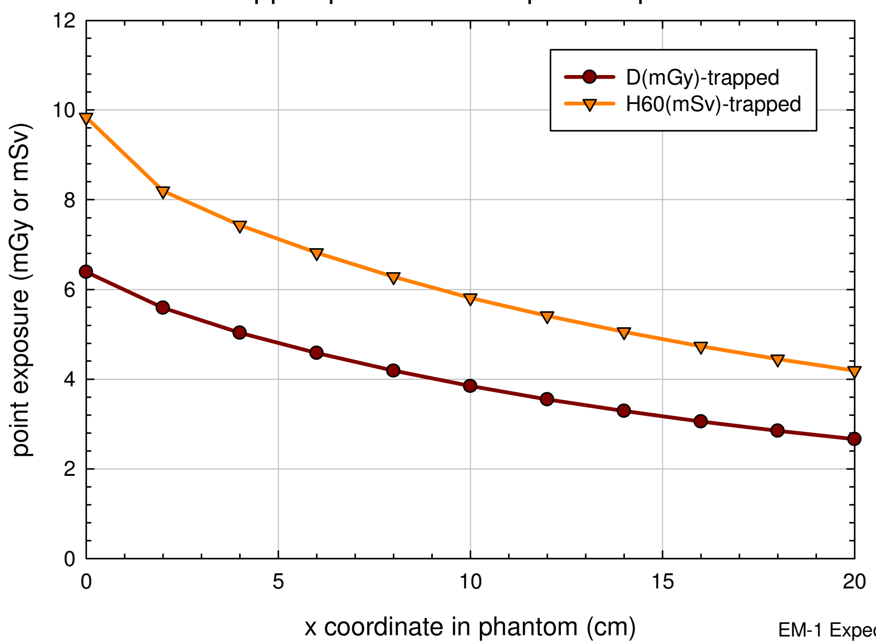
EM-1 Uncrewed Distant Retrograde Orbit (DRO) Mission Overview



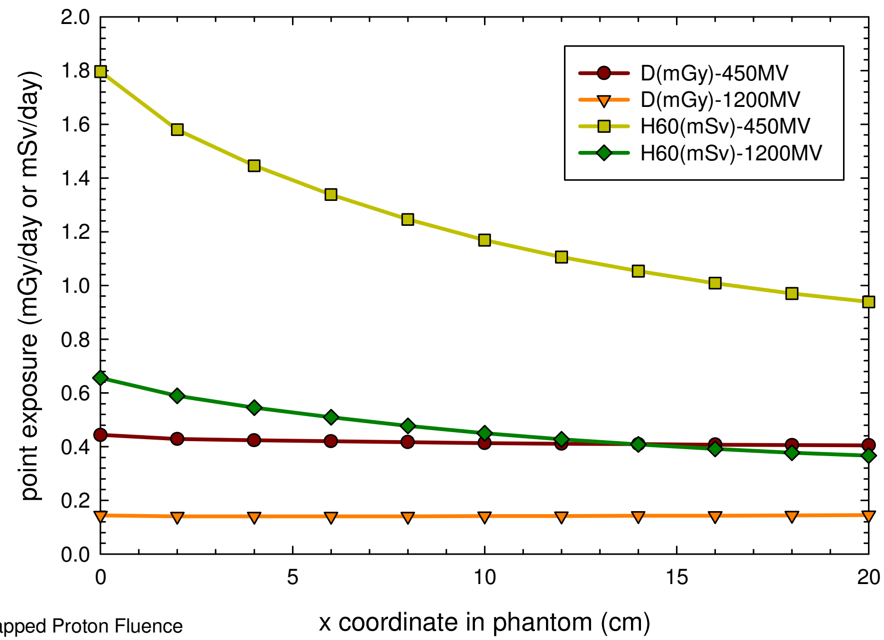
Predicted MARE doses

- **HZETRN2015, slab geometry 10.7 Al - x H2O - 10.7 Al (g/cm²)**

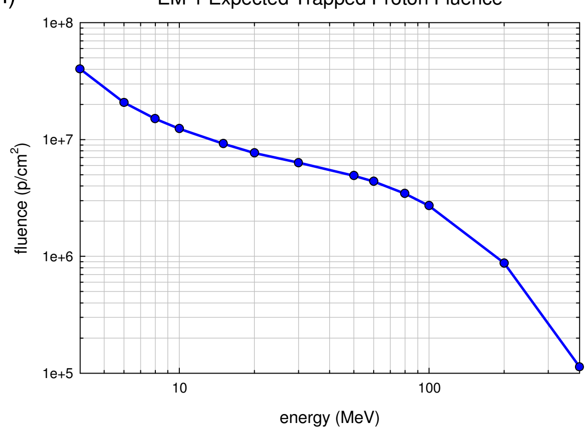
Trapped proton dose deposition profile



Daily GCR dose deposition profile

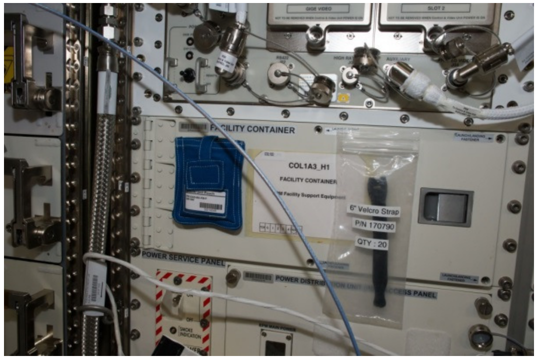


EM-1 Expected Trapped Proton Fluence



Active Detectors

- **DLR M-42 Silicon Detector**
- **NASA Crew Personal Active Dosimeter [NASA CPAD]**
  – Provision of up to 16 CPADs for MARE
- **ESA Active Dosimeter [Orion EAD MU] PI: Ulrich Straube ESA-EAC**
  – Upgrade of EAD Mobile Units for ORION EM-1 Flight Requirements
  – Provision of up to 3 EAD MU-O for MARE



MARE: The DLR M-42 radiation detector for MARE

Biophysics Group
Radiation Biology Department
Institute of Aerospace Medicine
German Aerospace Center (DLR)
Linder Hoehe
51147 Cologne
Germany

MARE: DLR-ME-SBA → M-42

M-42: Radiation sensor based on ORION EM-1 Requirements

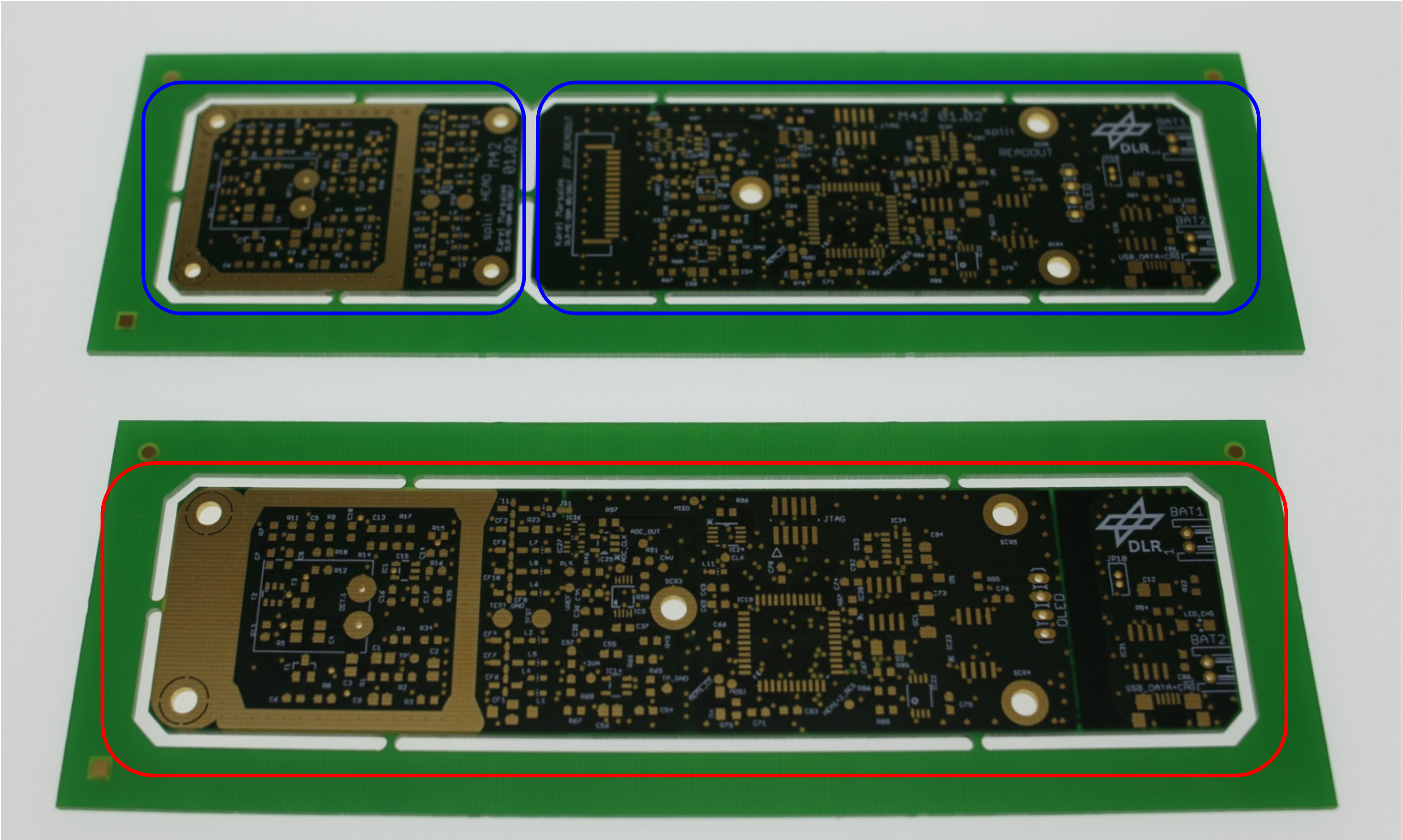
- Autonomous operations
- Battery operated [>= 43 days runtime]
- Launch detection [Accelerometer]
- NASA + NAVY Safety Standards

  - M-42 shall measure the radiation environment during the ORION EM-1 mission within and outside the female MTR Phantoms
    - Silicon Detector:

Area:	1 cm^2
Thickness:	300 µm
Energy range:	0.06 – 20 MeV in Si
Channels:	1024

MARE: DLR-ME-SBA → M-42

M-42: SPLIT / COMPACT



MARE: DLR-ME-SBA → M-42

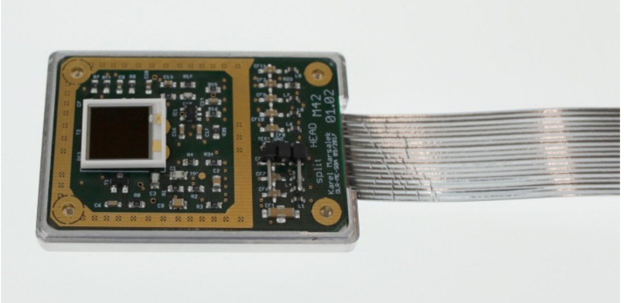
M-42: SPLIT [M-42_S]

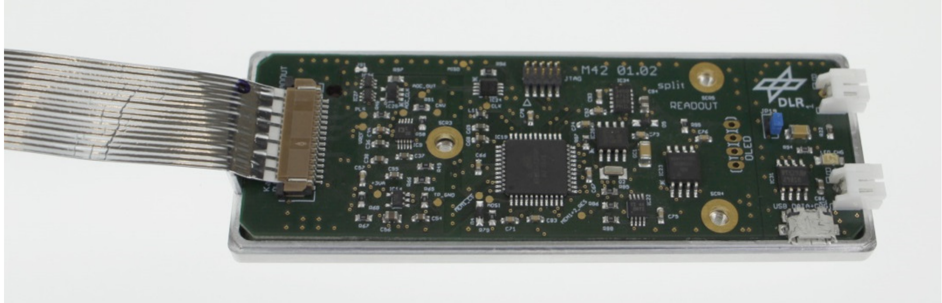
M-42_S: Detector: 54 x 38 x 13 mm^3 M-42_S: Electronic box: 106 x 38 x 13 mm^3

Total mass: 120 g

MARE: DLR-ME-SBA → M-42

M-42: SPLIT [M-42_S]





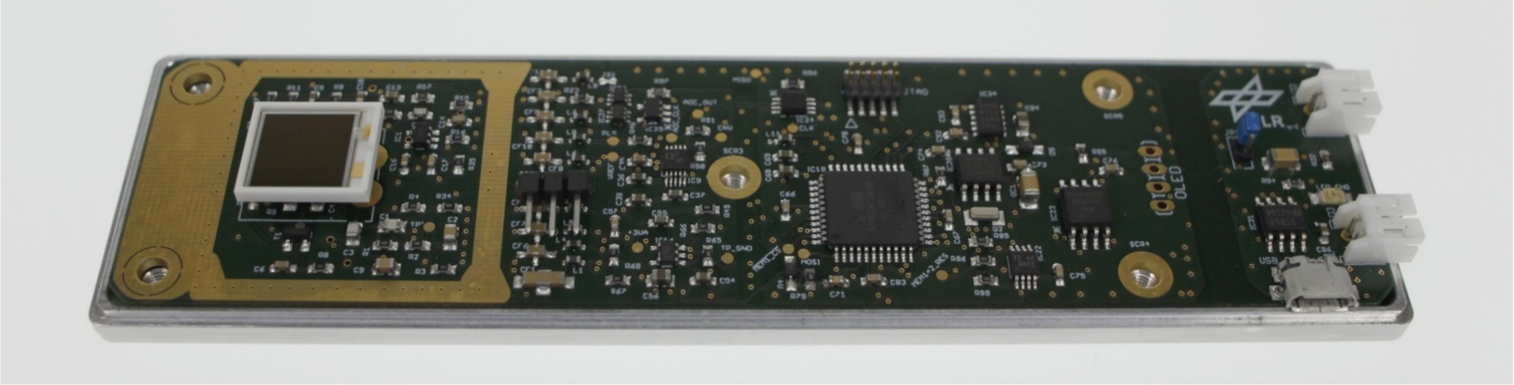
MARE: DLR-ME-SBA → M-42

M-42: COMPACT [M-42_C]

M-42_C: 142 x 38 x 13 mm^3
Total mass: 108 g

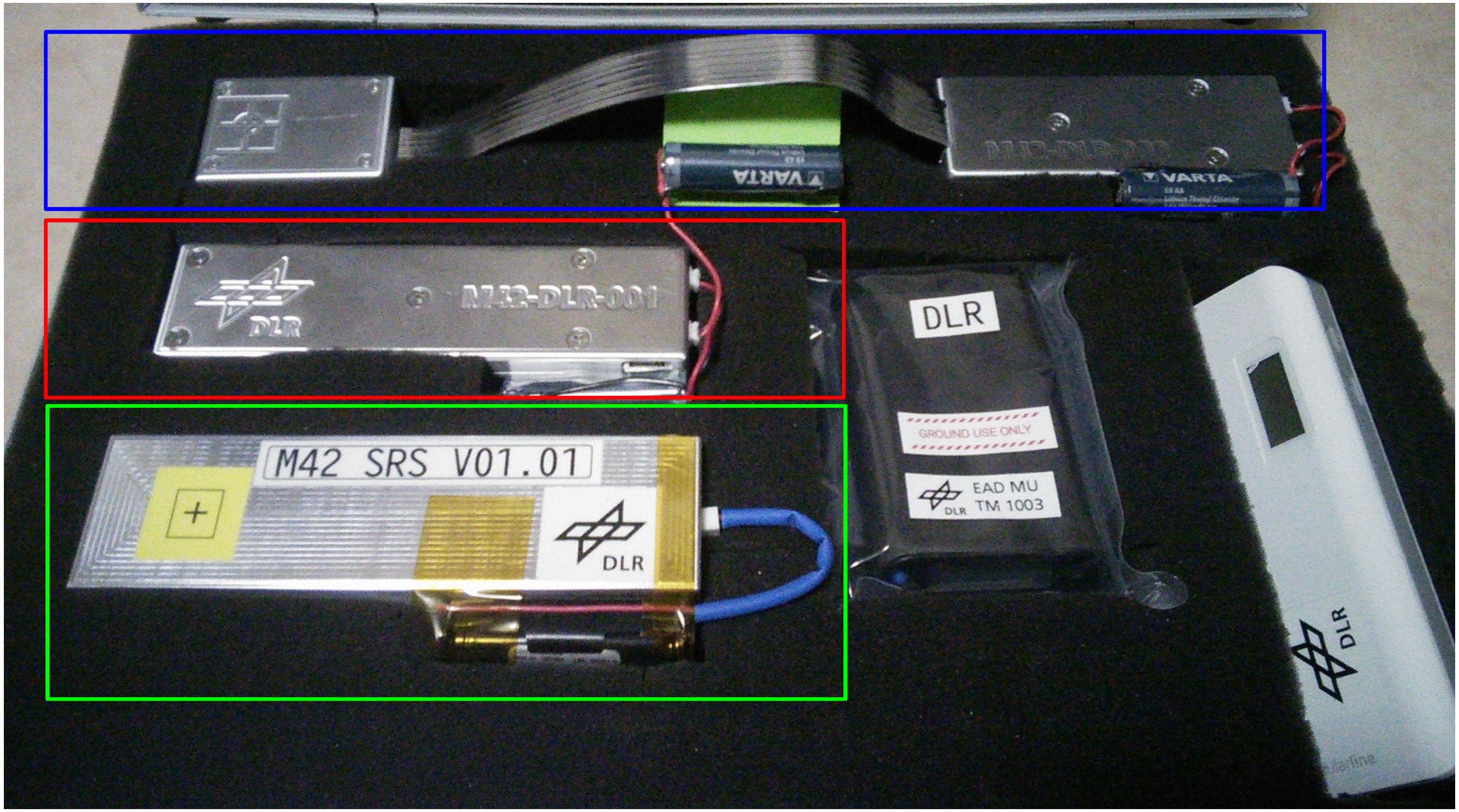
MARE: DLR-ME-SBA → M-42

M-42: COMPACT [M-42_C]



MARE: M-42 / Flight DUS-NRT ←→ NRT-DUS

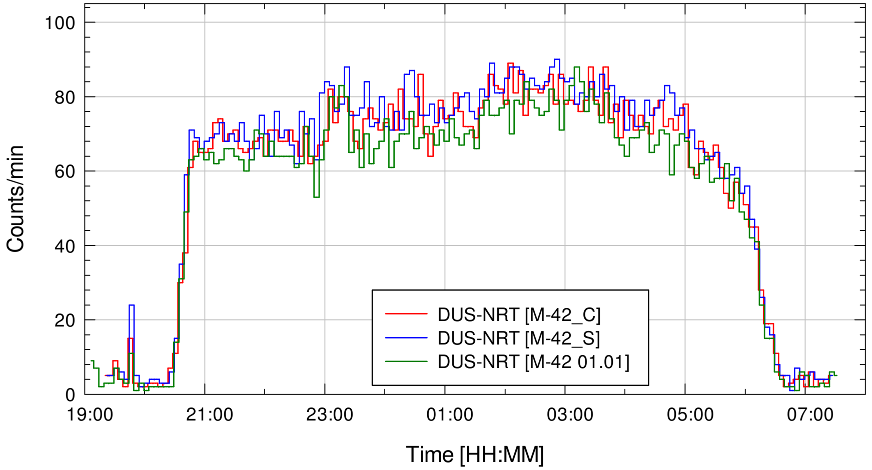
M-42: Overview M-42 01.01 [Prototype] & M-42_C and M-42_S [2nd Generation]

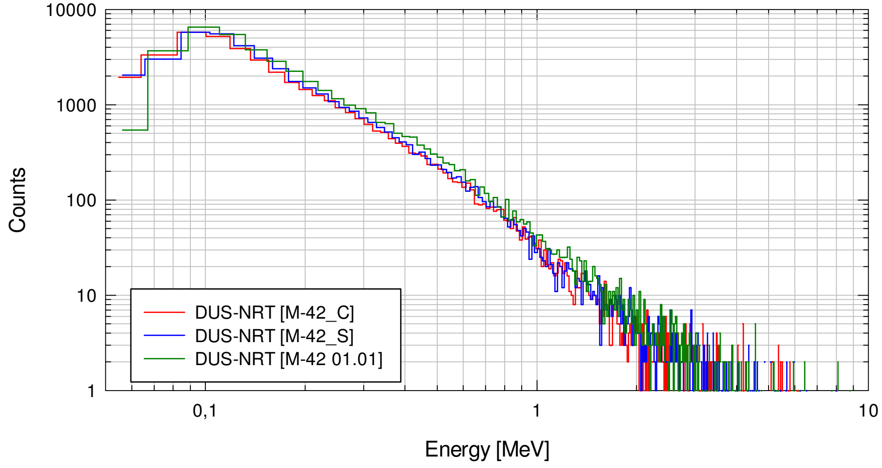


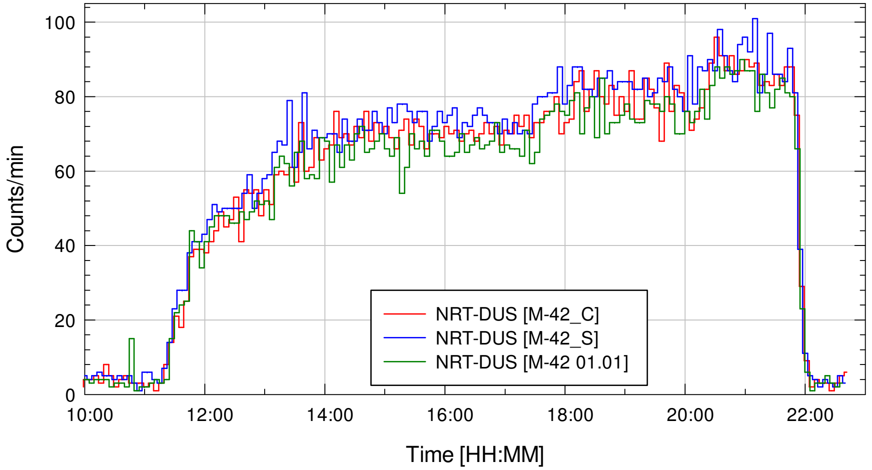
DLR

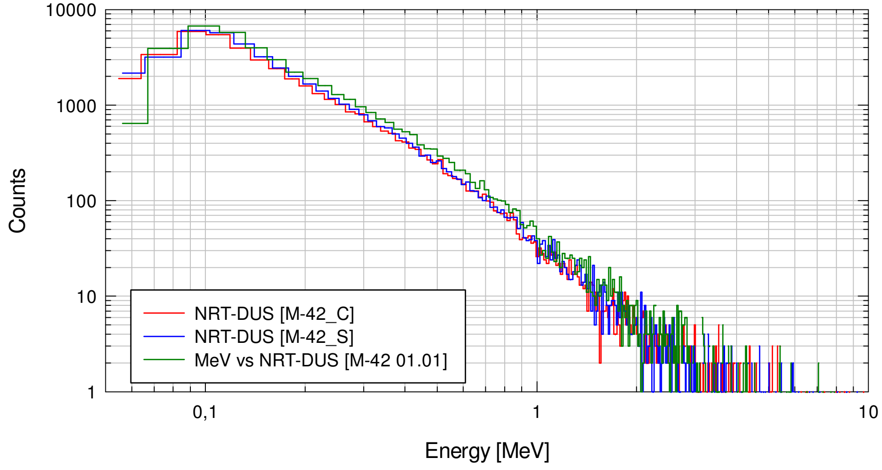
MARE: M-42 / Flight DUS-NRT ←→ NRT-DUS

M-42: M-42 01.01 [Prototype] & M-42_C and M-42_S [2nd Generation]



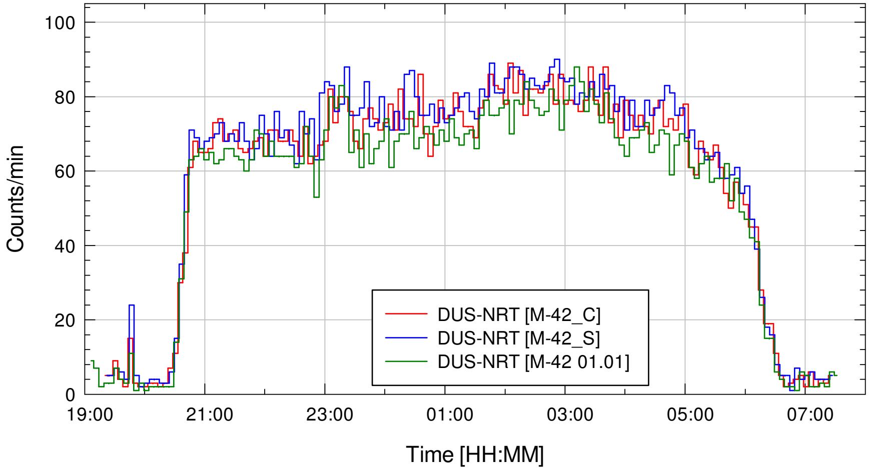


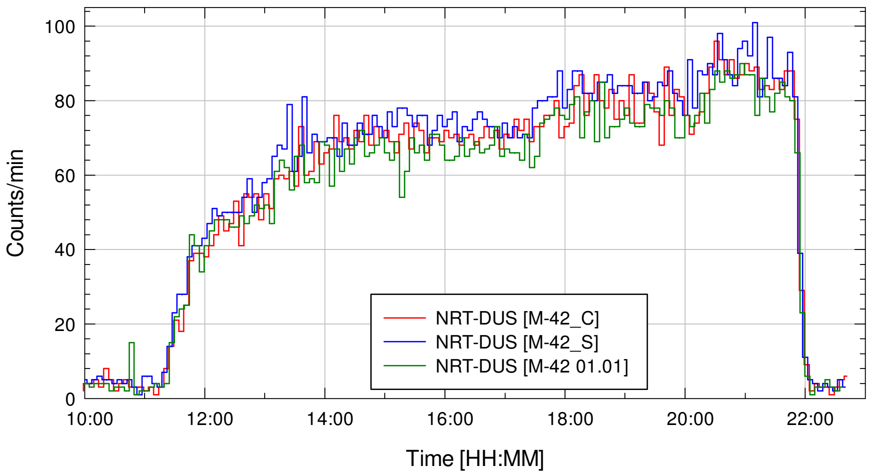


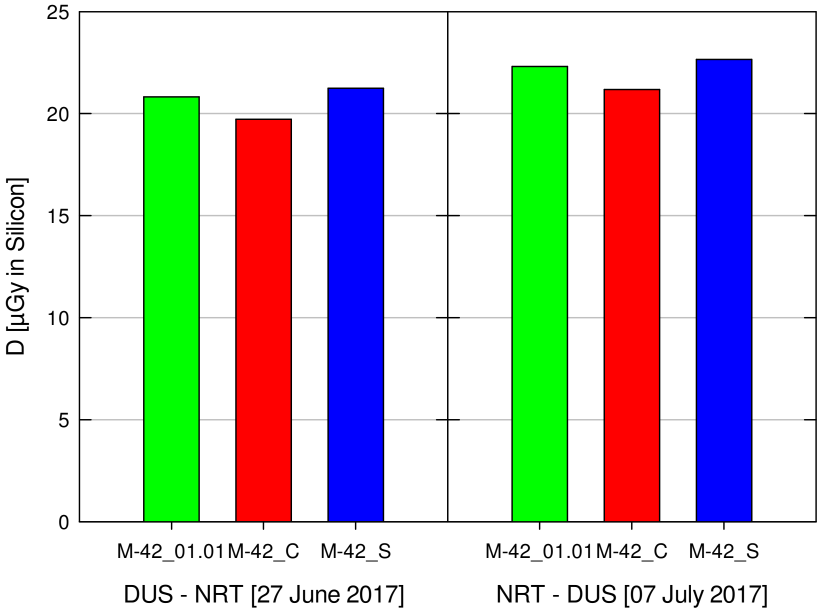


MARE: M-42 / Flight DUS-NRT ←→ NRT-DUS

M-42: M-42 01.01 [Prototype] & M-42_C and M-42_S [2nd Generation]





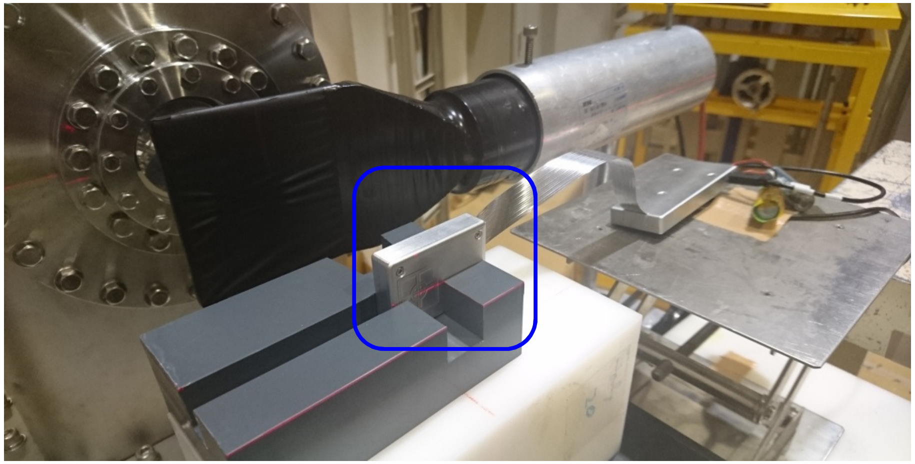


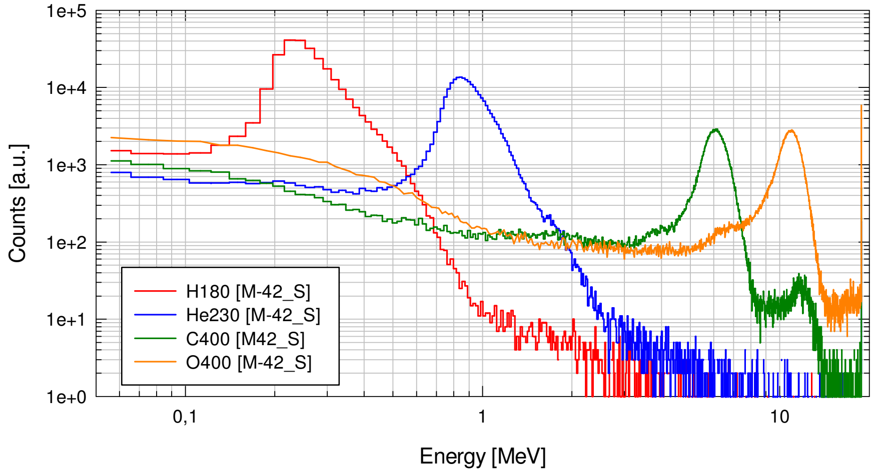
DUS-NRT: 20.56 ± 0.78 µGy in Si

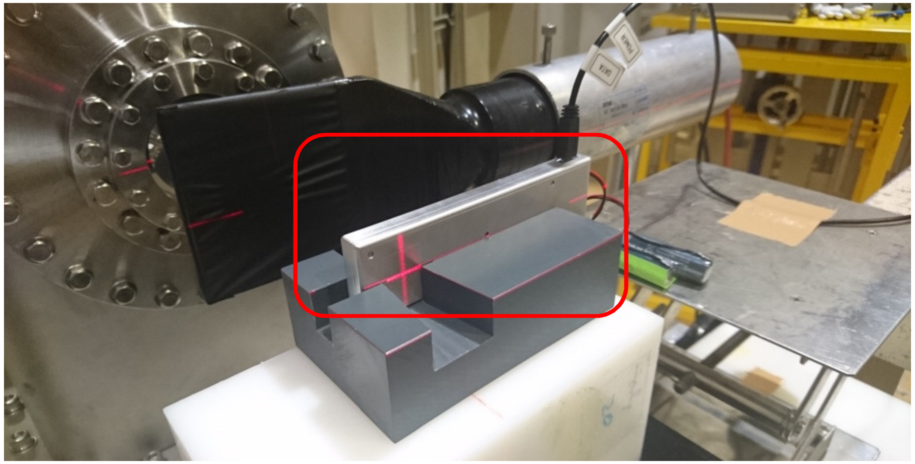
NRT-DUS: 22.07 ± 0.77 µGy in Si

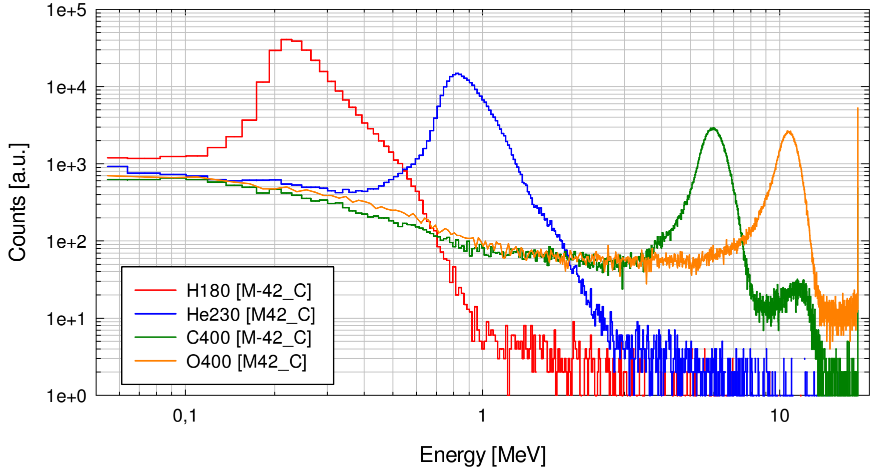
MARE: M-42 / HIMAC Beam time

HIMAC Research Project: 17H374 / M-42_S and M-42_C in the HIMAC Physics Room









DLR

MARE: M-42 / Battery Test

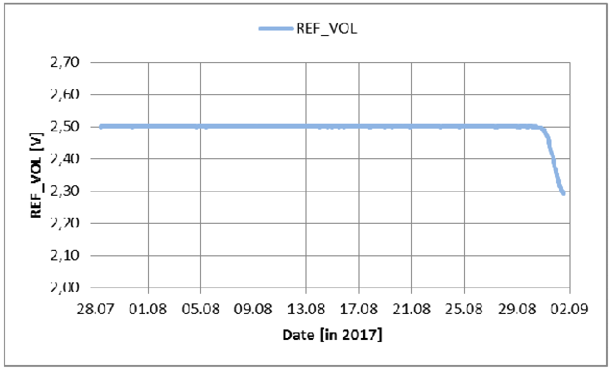
M-42: M-42_S / Long term test of one VARTA ER AA 3.6V 2500mAh Battery

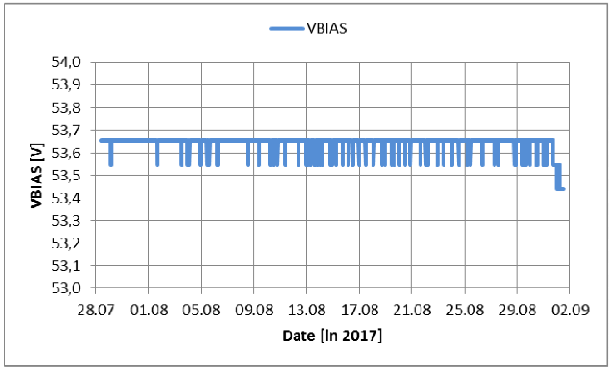
- **AIM:** Test the battery lifetime of one VARTA ER AA 3.6V 2500mAh Battery with the current system (~2.8mA)
- **LOG:** Internal H/K data as well as count rate data battery voltage are logged every 5 minutes
- **LOG:** Energy deposition spectra are summed up over the time of the measurements
  - **START:** Friday 27 July 2017
  - **END:** Friday 01 September 2017
  - **DURATION:** 34 days

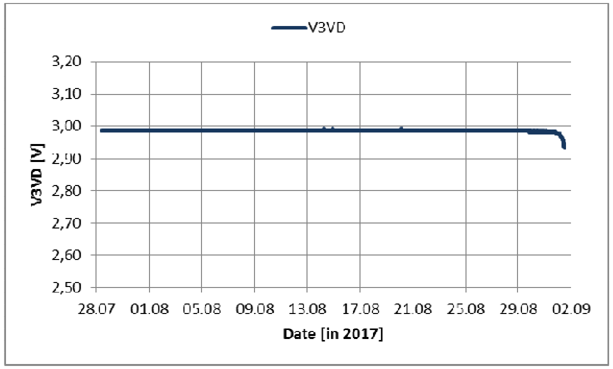
MARE: M-42 / Battery Test

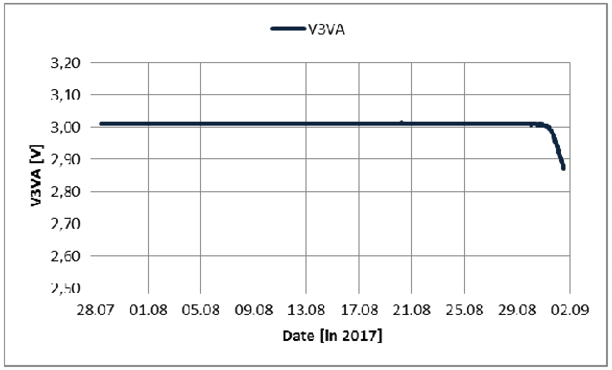
M-42: M-42_S / Long term test of one VARTA ER AA 3.6V 2500mAh Battery

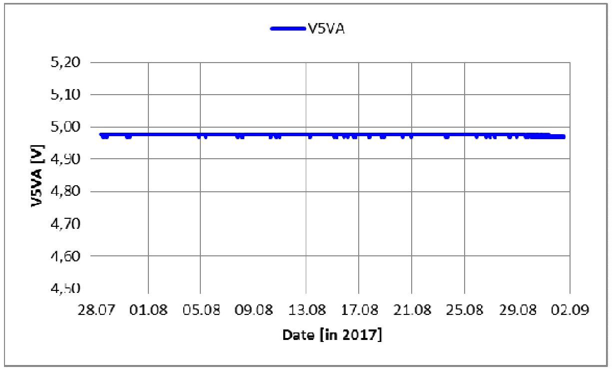
VOLTAGES







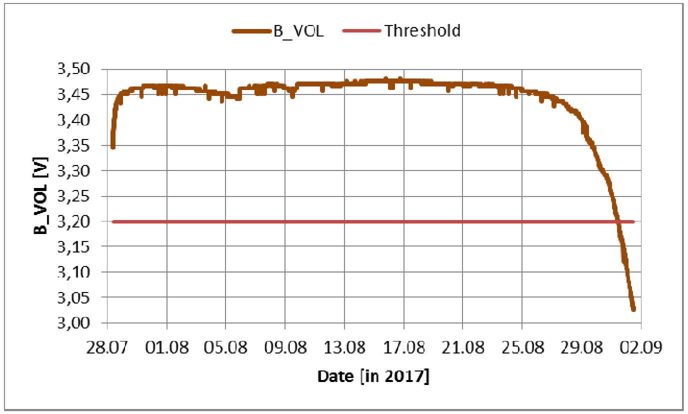




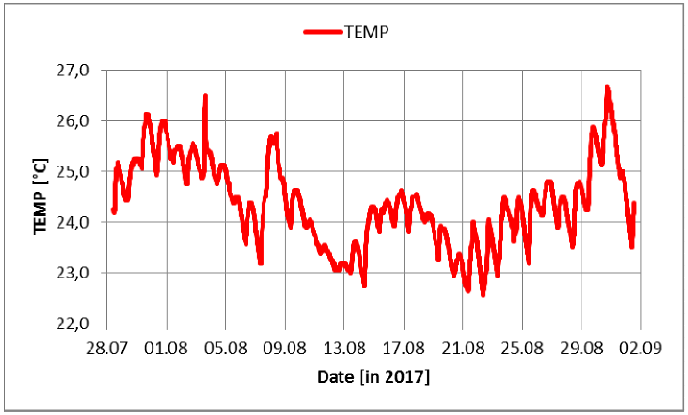
MARE: M-42 / Battery Test

M-42: M-42_S / Long term test of one VARTA ER AA 3.6V 2500mAh Battery

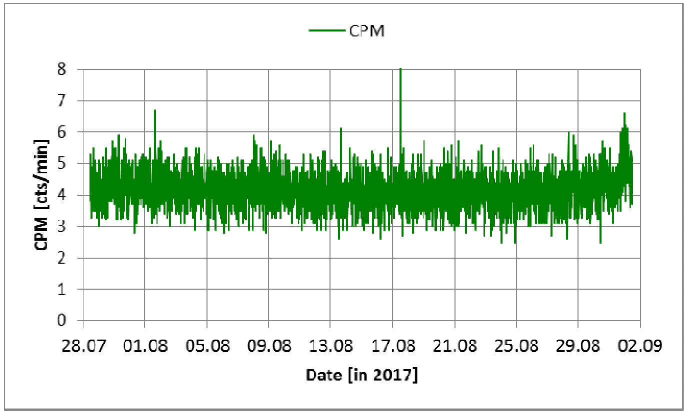
BATTERY VOLTAGE



TEMPERATURE



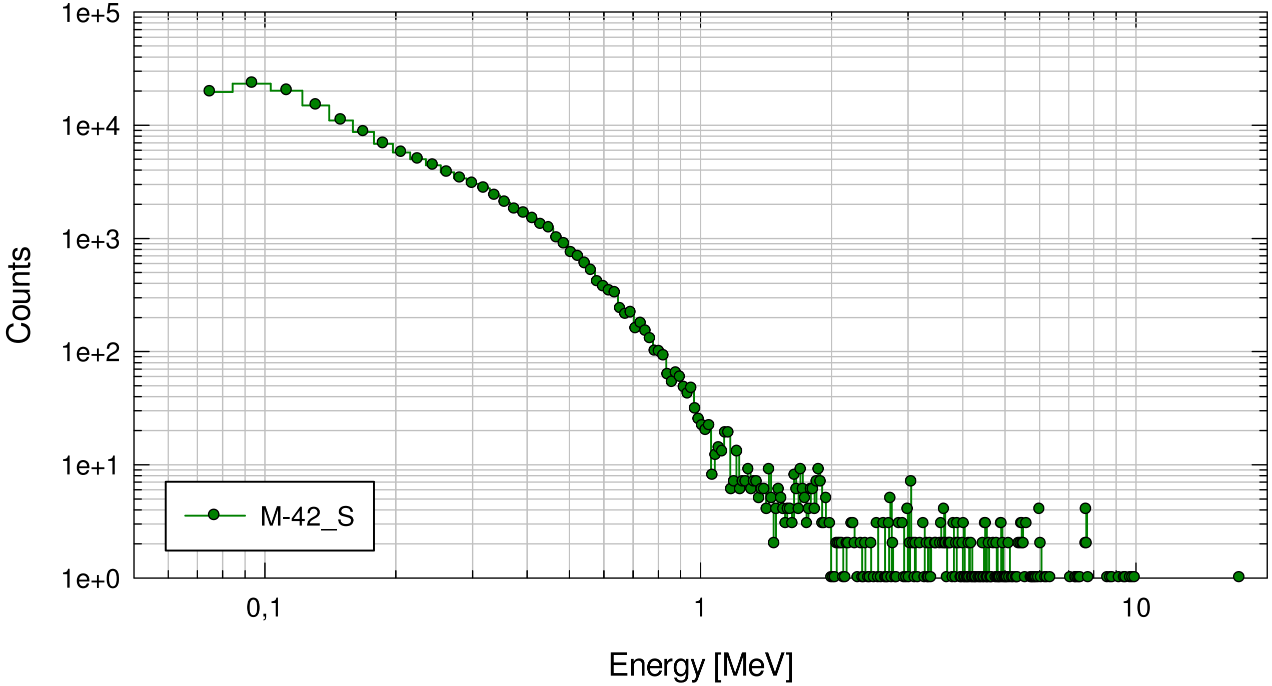
COUNT RATE



MARE: M-42 / Battery Test

M-42: M-42_S / Long term test of one VARTA ER AA 3.6V 2500mAh Battery

Energy deposition spectra

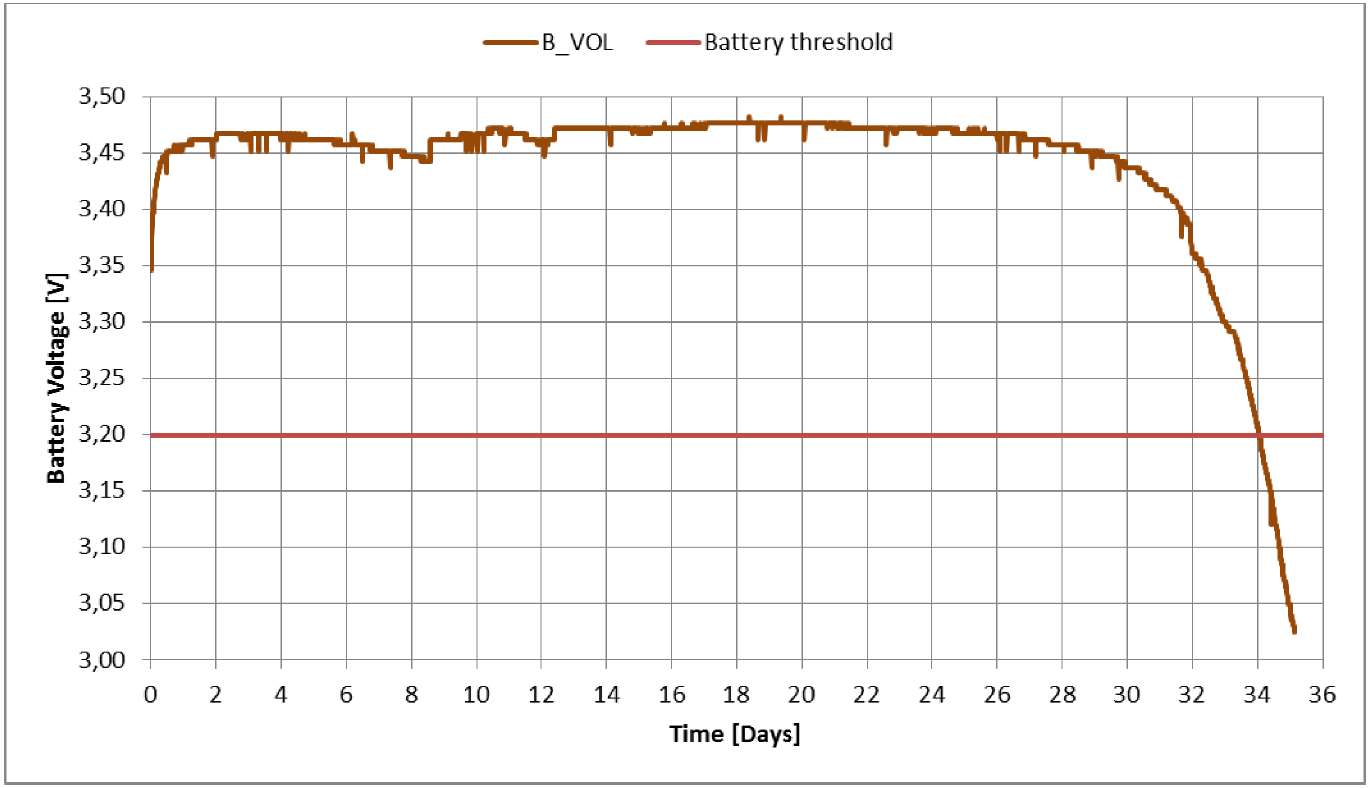


Dose [µGy/day]: 78.6 nGy/h (Si) = 1.89 µGy/d (Si)

MARE: M-42 / Battery Test

M-42: M-42_S / Long term test of one VARTA ER AA 3.6V 2500mAh Battery

Total battery life time: 34 days



DLR

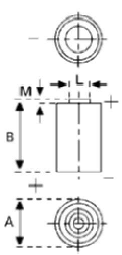
VARTA

ER AA

Lithium Thionyl Chloride

Data Sheet

Type Designation	ER AA
Type Number	7106
Designation IEC	14500
System	Primary Li-Thionyl Chloride / Li-$SOCl_2$
UL Recognition:	MH 13654
Nominal Voltage	3.6 V
Typical Capacity C Load 2 mA, at 20°C, down to 2.0 V	2500 mAh
Max continuous discharge current to get 50% of nom. cap +20°C, down to 2.0V	60 mA
Max pulse discharge current*	150 mA
Weight (approx.)	16 g
Volume	8,5 ccm
Coding	Date of Manufacturing Year / Month



Temperature Ranges	min	max.
Operating	-55°C	85°C

Dimensions	min	max.
Diameter (A)	14,0	14,6
Height (B)	50,0	50,5
Shoulder Diameter [L]	4,6	4,8
Shoulder Height [M]	0,9	

Li metal content Approx. 0.62 g

*Max. pulse current / 0.1 second pulses, drained every 2 min at +20°C from undischarged cells with 10 μA base current, yield voltage readings above 3.0 V. The readings may vary according to the pulse characteristics, the temperature, and the cell's previous history. Fitting the cell with a capacitor may be recommended in severe conditions.

WARNING: Fire, explosion and severe burn hazard. Do not recharge, crush, disassemble, heat above 100°C (212°F), incinerate, short circuit or expose contents to water. Keep battery out of reach of children and in original package until ready for use. Dispose of used batteries properly.

Internal resistance may rise versus time, especially in case of exposure to elevated temperature

Information and contents in this data sheet are for reference purpose only.
They do not constitute any warranty or representation and are subject to change without notice.
For most current information and further details, please contact your VARTA representative.

VARTA Microbattery GmbH, Daimlerstr. 1, D-73479 Ellwangen/Jagst
Tel.: (+49) 7961/921-0, Telefax: (+49) 7961/921-553
Subject to change without prior notice!
Date of issue: 2014-09-18

VARTA

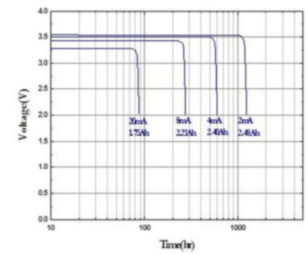
ER AA

Lithium Thionyl Chloride

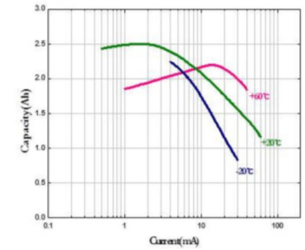
Data Sheet

Performance Data:

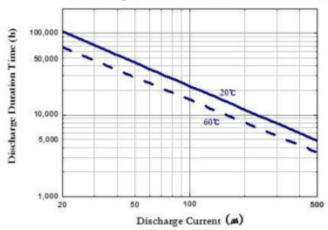
- Continuous Discharge at 20°C



- Capacity vs. Current



- Discharge Current vs. Duration Time



This data was made on basis of nominal capacity for the purpose of enabling users to forecast approximate life time. In order to calculate precise life time under various environments, we recommend you to consult VARTA Microbattery GmbH. In case where the products are improved, the specifications described herein are subject to change.

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Subject to change without prior notice!
Date of issue: 2014-09-18

Passive Detectors

- **A combination of passive TLD/OSLDs and Nuclear Track Etch Detectors will be used for the determination of D and H:**
  - Determine skin dose
  - Determine depth dose distribution inside the phantom
  - Determine organ dose at relevant organ location
  - Determine "environmental" dose at the location of the phantoms
- **Most detectors will be provided by DLR and NASA JSC SRAG**
- **Passive detector group will include contributions from DOSIS 3D team members:**
  - Technical University Vienna, ATI, Austria
  - Institute of Nuclear Physics, IFJ, Krakow, Poland
  - Centre for Energy Research, MTA EK, Budapest, Hungary
  - Belgian Nuclear Research Center, SCK•CEN, Mol, Belgium
  - Nuclear Physics Institute, NPI, Prague, Czech Republic
  - Oklahoma State University, OSU, Stillwater, USA
  - National Institute of Radiological Sciences, NIRS; Chiba, Japan

MARE Path Forward

- **Interagency agreements**
- **Integrated Requirements and Interface Control Document (IRICD)**
- **Detector complement refinement**
- **Payload development and Orion integration activities**
  - **EM-1 Flight**
- **Post-flight data analysis**
  - Environment modeling
  - Spacecraft shielding analyses
  - Organ dose measurements vs. predictions
  - Quantification of protection benefit of AstroRad
  - Comparison with other detectors inside Orion
  - Joint publications

Conclusion

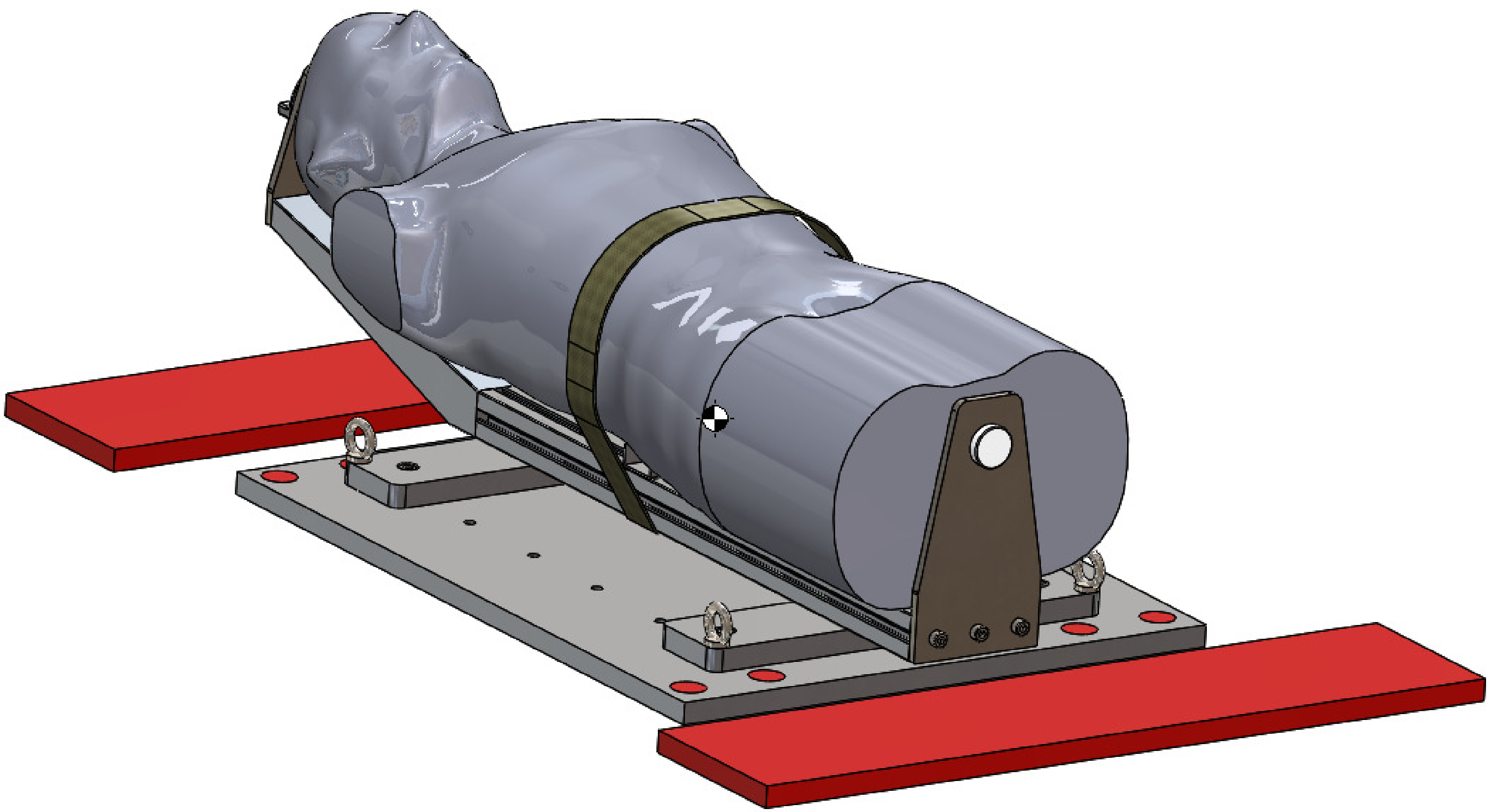
- MARE is among the first Orion payloads
- International collaboration
- Orion is the next generation platform for space science & research

The goal is to improve astronaut safety and enable Exploration

Backup

Mechanical Integration

- **Bracket developed by DLR**



Mechanical Integration

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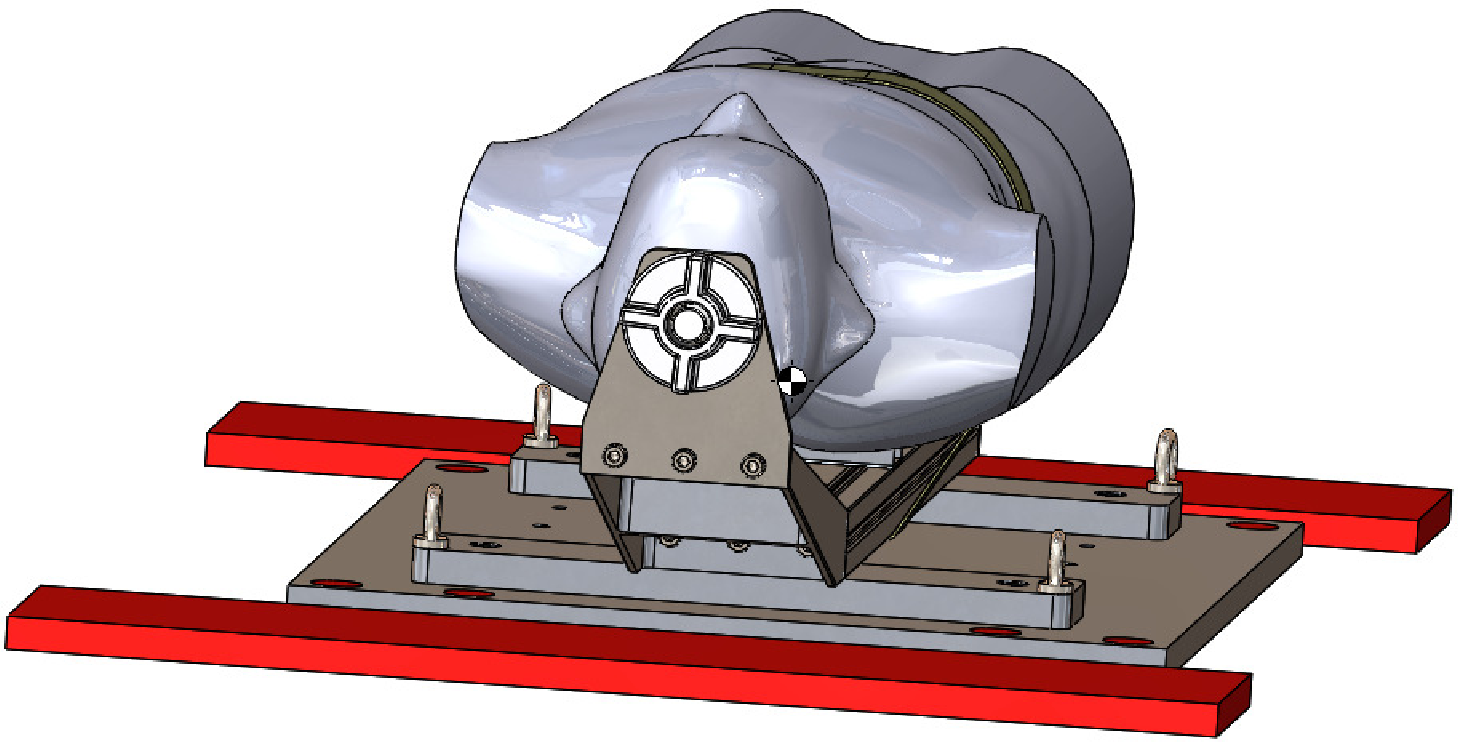
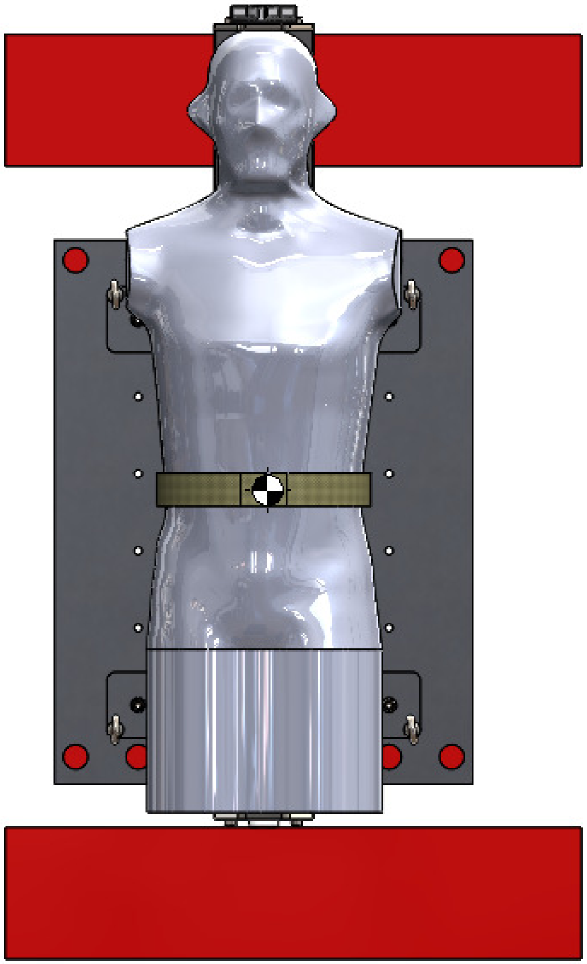
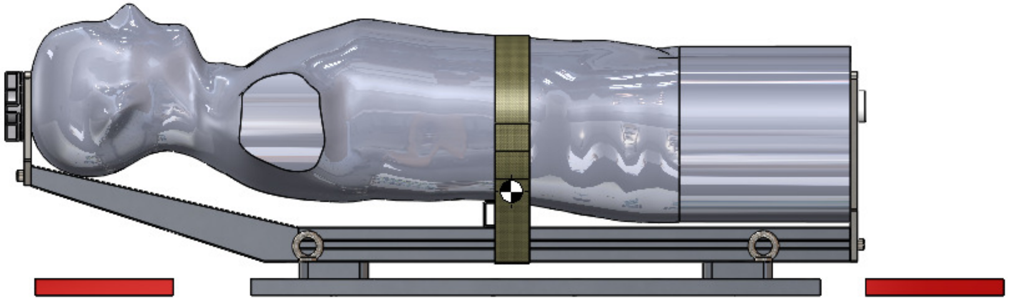


Mechanical Integration

- **Bracket developed by DLR**





Mechanical Integration

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