MARE International Payload aboard Orion EM-1 Status Update for 23rd WRMISS

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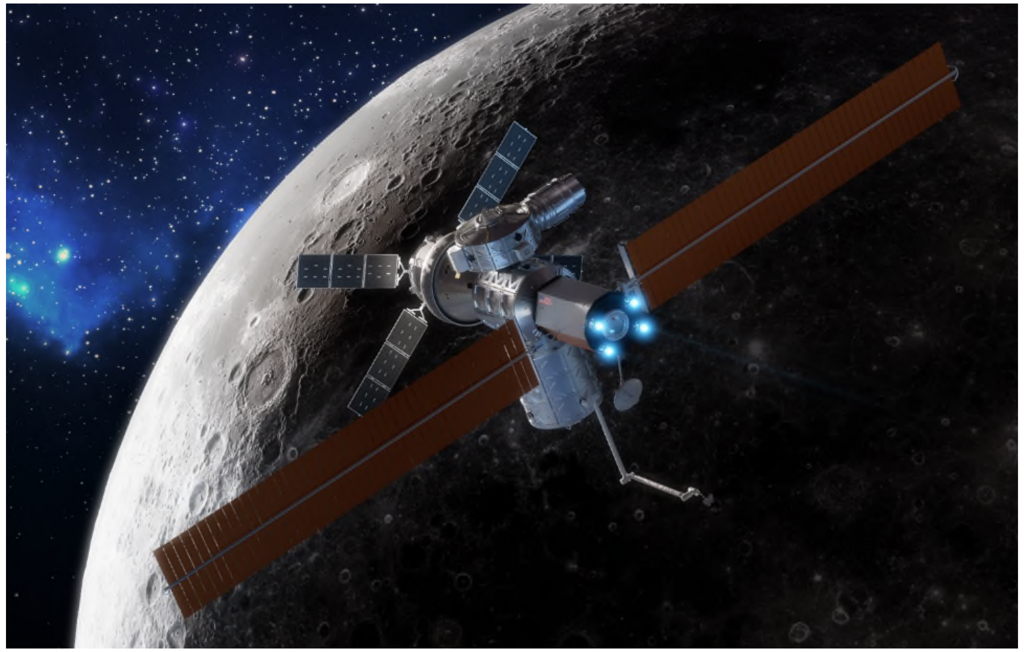
Presentation Outline

- **Orion background, radiation requirements, and design for ALARA**
- **AstroRad individual radiation shield**
- **Matroshka AstroRad Radiation Experiment (MARE)**

Orion MPCV

- **The Orion Multipurpose Crew Vehicle (MPCV) is NASA's next generation spacecraft for human exploration of the solar system**
- **Exploration Flight Test 1 (EFT-1) successfully executed December 2014**
  - High eccentricity high altitude orbit to 3600 mi
- **Exploration Mission 1 (EM-1) scheduled 2020**
  - 21-42 days mission to Cis-lunar space
- **Exploration Mission 2 (EM-2) first crewed flight scheduled 2022**
  - Gateway elements (Power and Propulsion Element PPE) will begin launching in 2022


Image Credit: NASA

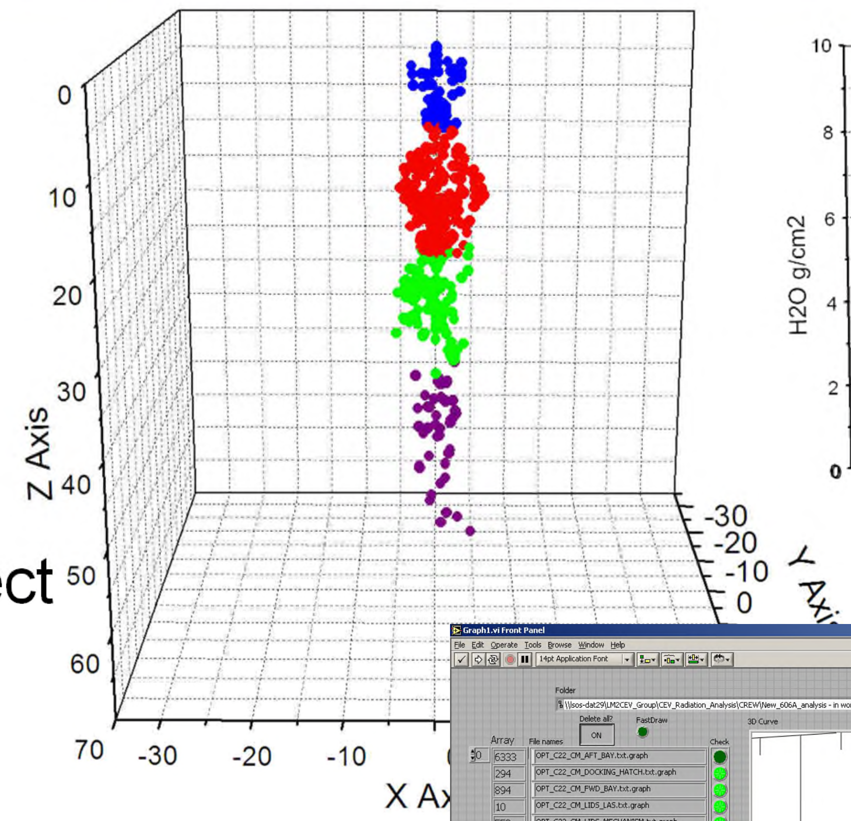


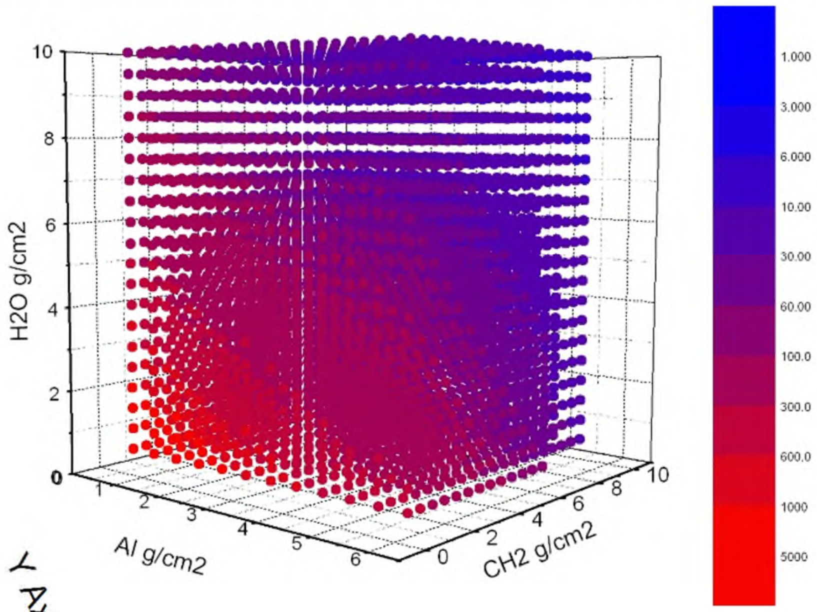
Orion Radiation Requirements

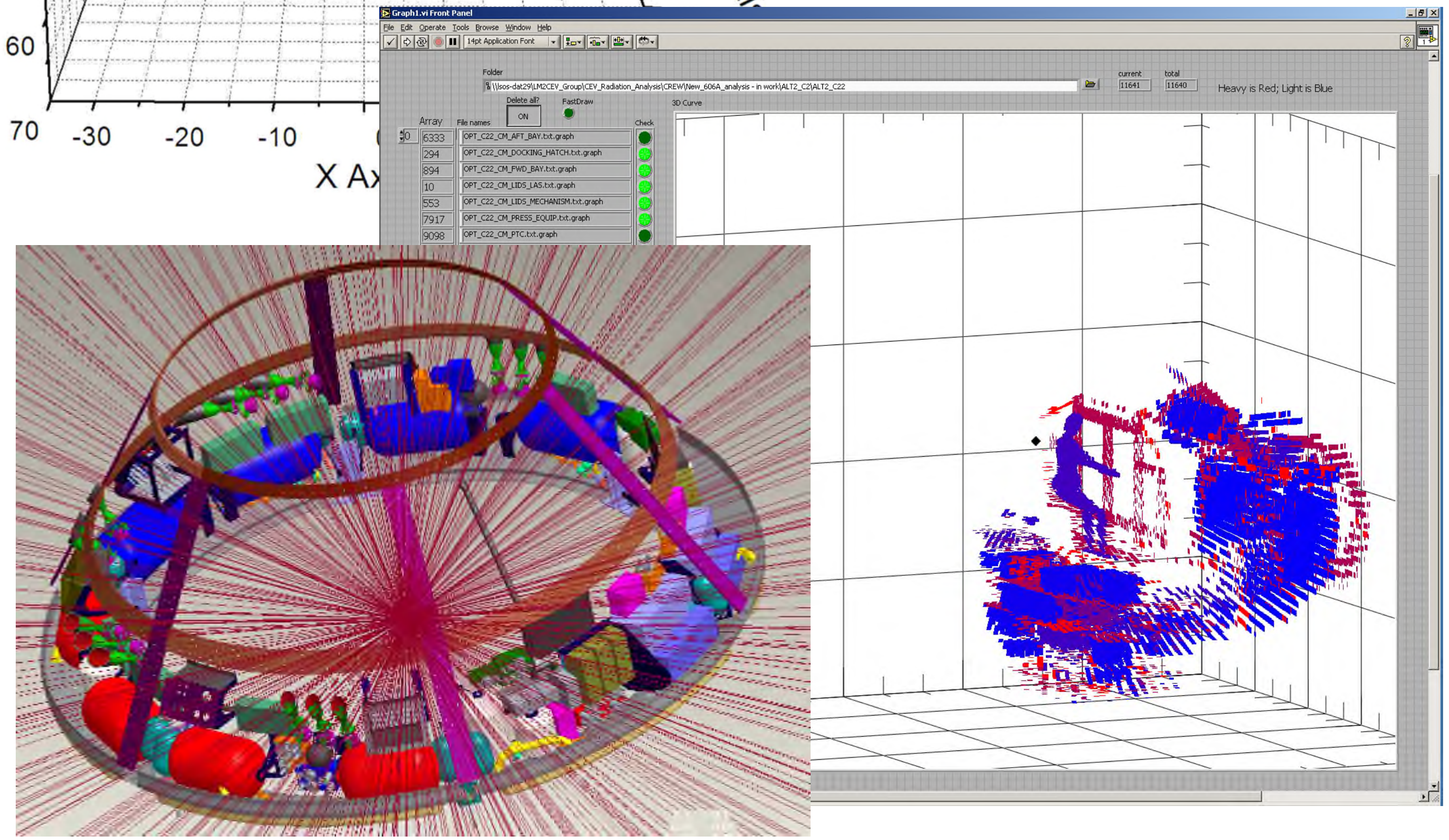
- **Hardware radiation protection (survivability)**
  - "Orion shall meet its functional, performance, and reliability requirements during and after exposure to the mission radiation environment" (Systems Requirements Document SRD)
  - Further decomposed in the Ionizing Radiation Control Plan (IRCP)
- **Crew radiation protection**
  - First NASA spacecraft on which Crew radiation protection is levied as a design driving requirement
  - Human Systems Integration Requirements, Design Specification for Natural Environments
  - Spacecraft design "shall provide radiation protection consistent with ALARA and not to exceed crew exposure of E = 150 mSv for design reference environment"
    - Aug 1972 Solar Particle Event SPE (King parameterization)
- **Evolution of radiation protection requirements beyond Orion**
  - Townsend et al., Life Sciences in Space Research 17 (2018) 32–39
  - BFO limit of 250 mGy-equivalent for the design SPE chosen as Oct 1989
  - ALARA, storm shelter availability within 30 min of event onset

Orion Requirement Verification

- **Radiation Analysis**
  - Manufacturing quality Orion CAD model
    - 20,000 parts & assemblies, 100 GB
    - Mass/density and material properties
  - Vehicle shielding by ray tracing
    - 4 origin points/crew member, 10k directions
  - Body self-shielding from anatomically correct human models (~600 organ points)
  - Ray-by-ray total converted to 3-material equivalents (Al, HDPE, H_2O)
  - Point dose equivalent calculations by deterministic transport software HZETRN
    - Definition of design reference environment
  - Integrated to obtain organ dose equivalent
  - Effective dose calculated w/ tissue weighting factors per NCRP Report 132 (2000)

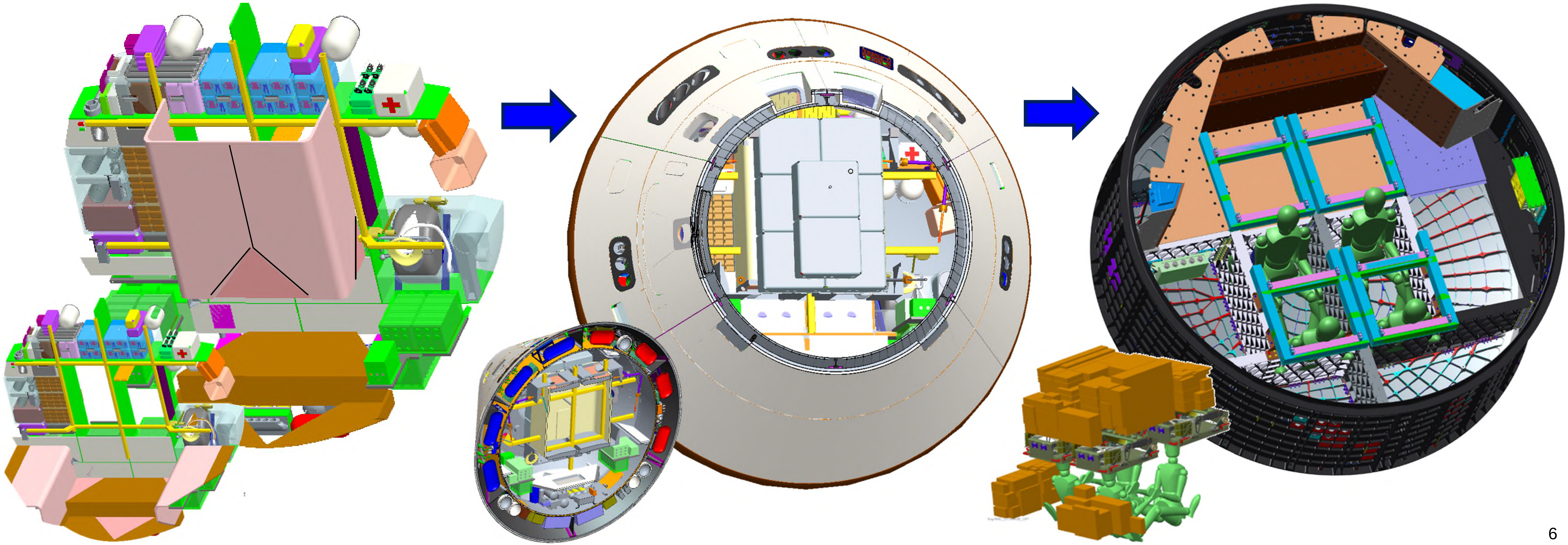






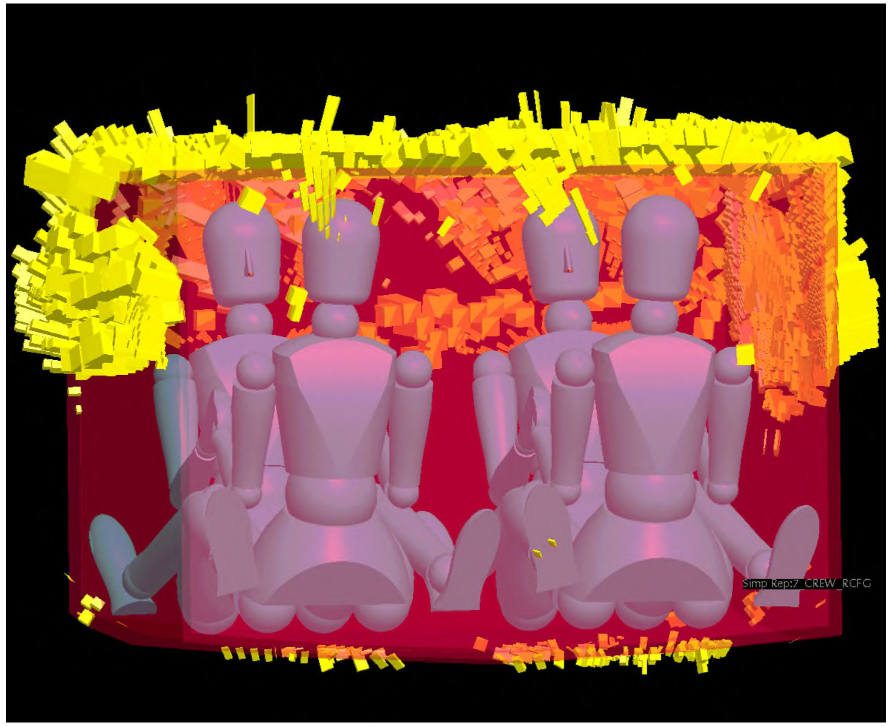
Orion Design for Crew Radiation Protection

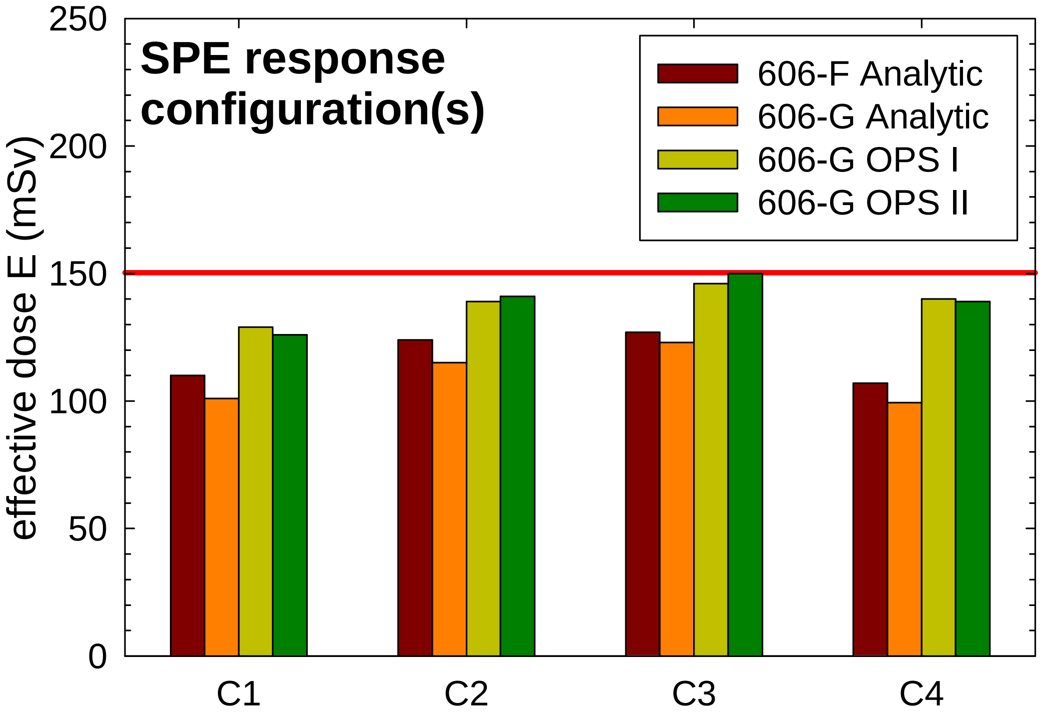
- **Matured throughout the vehicle design**
  - Early in the program the Master Equipment List included 254 lbm of Polyethylene radiation shield
  - Dedicated shielding mass was progressively reduced and ultimately eliminated
  - Current baseline relies on design and operational reconfiguration of cabin in case of SPE

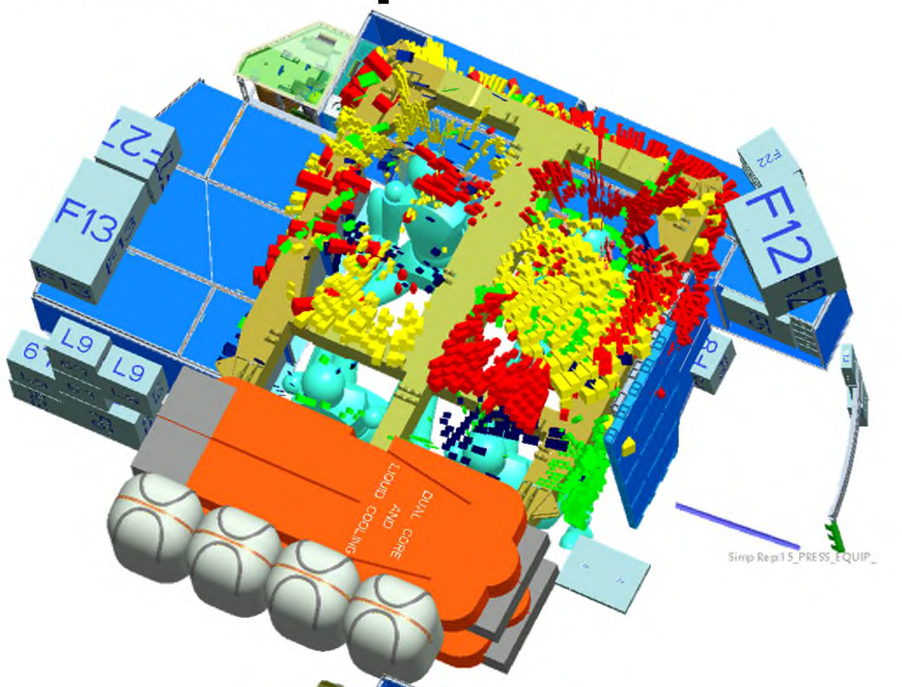


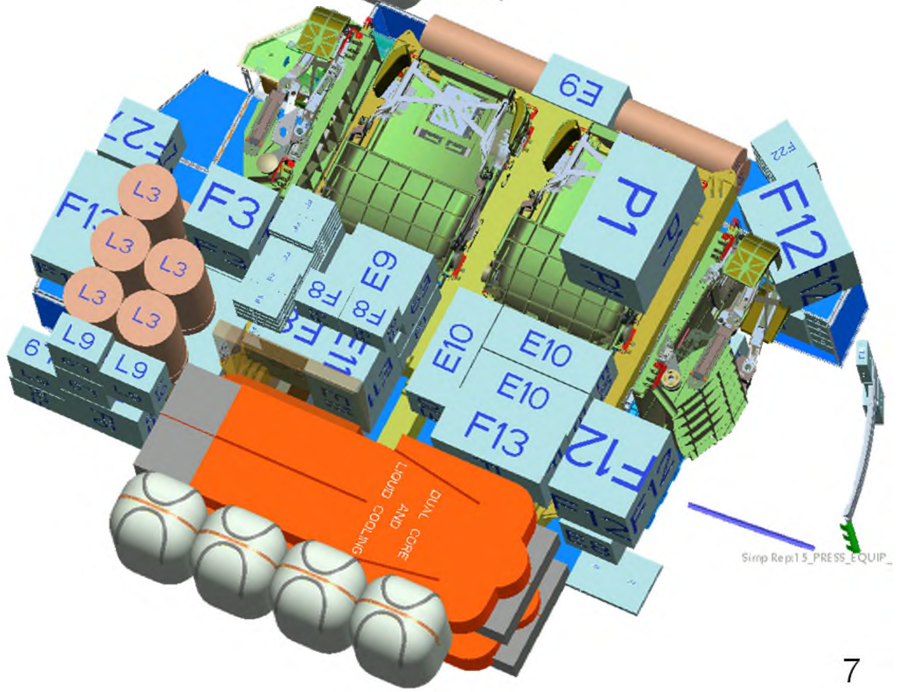
Cabin Configuration Optimization

- **Definition of cabin reconfiguration that maximizes crew radiation protection**
  - Consistent with ALARA
  - Large number of variables renders closed solution difficult
  - Semi-analytical method example: visualization of additional shielding location required to achieve predefined target shielding thickness endpoint









Radiation Shelter Evaluation

- **2016 Human In The Loop testing in the NASA JSC Orion med-fidelity mockup**

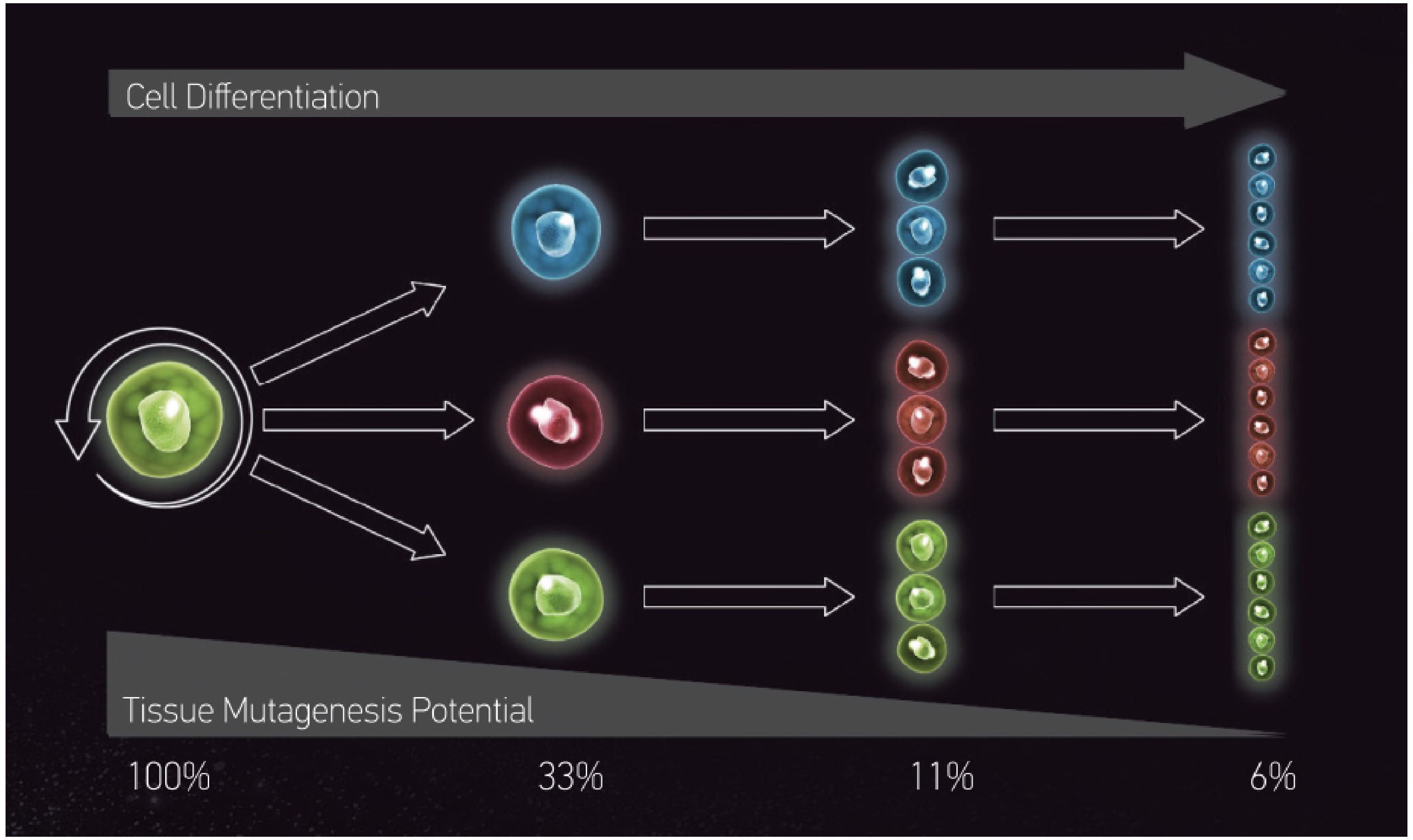
https://www.youtube.com/watch?v=70GrihLXmSs

Image Credit: NASA

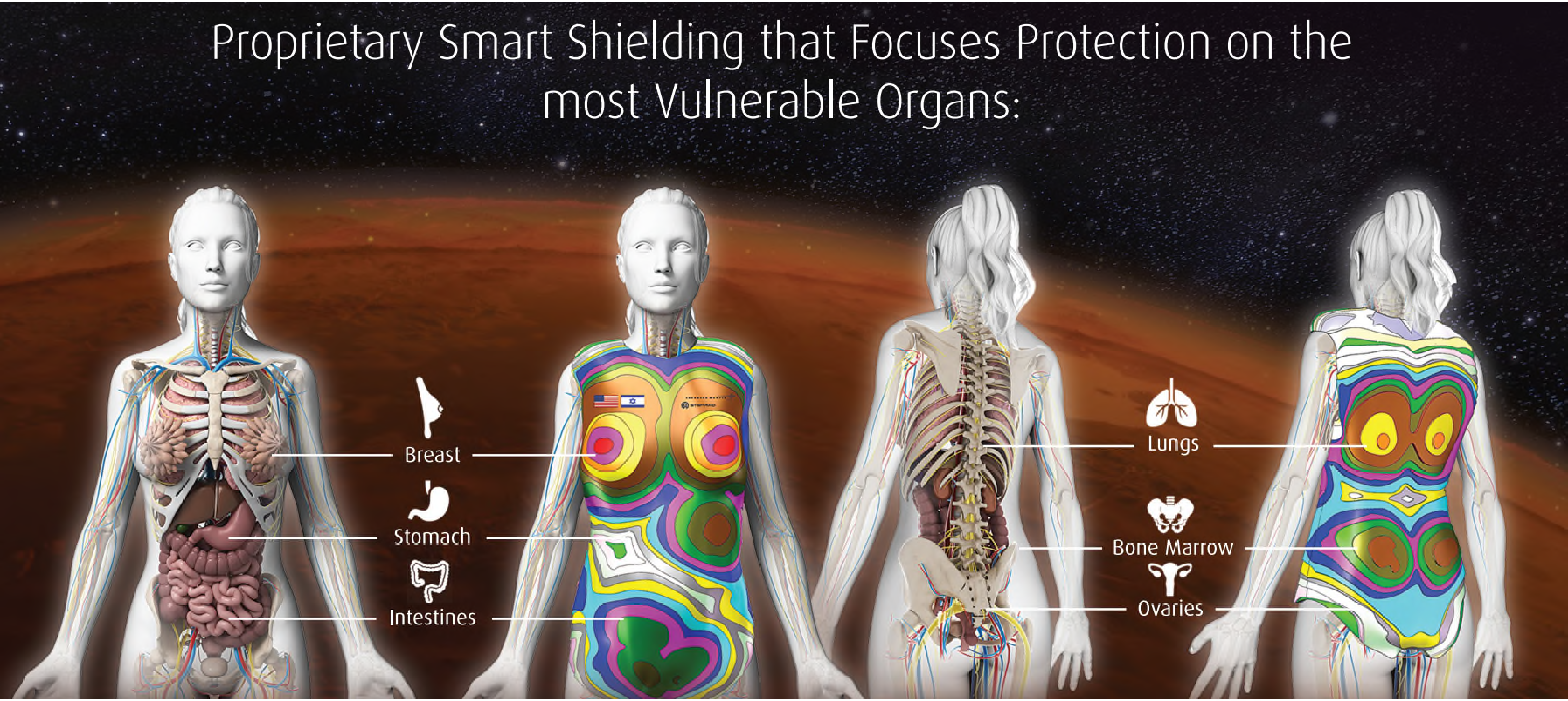
Image Credit: NASA

Radiation Vest for Astronauts: AstroRad

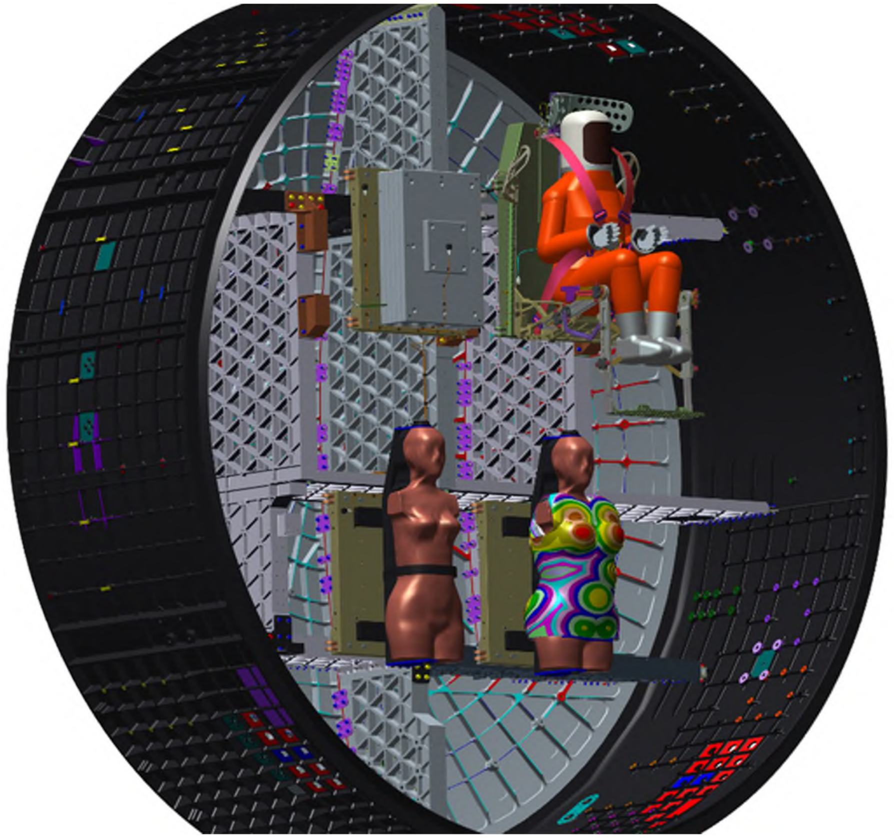
- **Collaboration between Lockheed Martin Space and StemRad Israel**
  - Portable radiation protection for astronauts
  - Provides preferential protection to stem cell rich organs and tissues
  - Designed for flexibility and ergonomics
  - Ergonomic evaluation planned aboard International Space Station



AstroRad

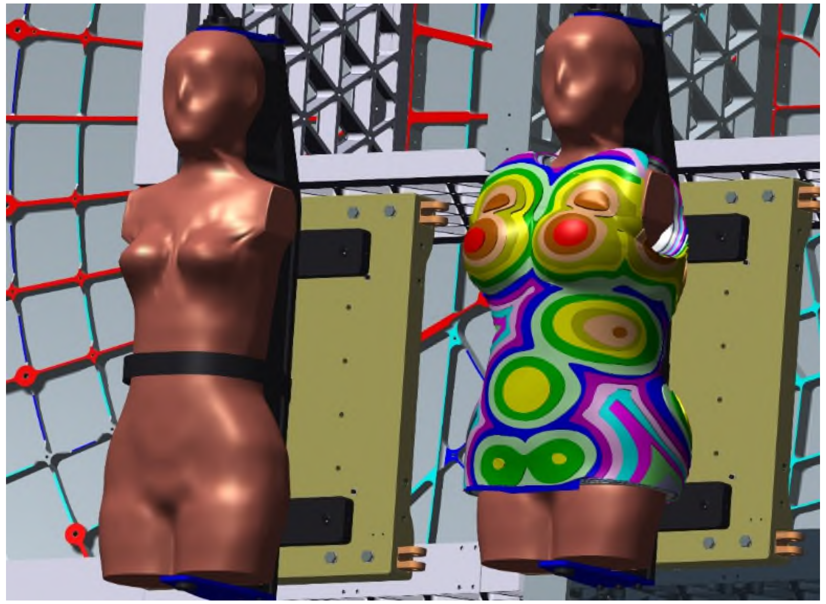

Proprietary Smart Shielding that Focuses Protection on the most Vulnerable Organs:
Breast
Stomach
Intestines
Lungs
Bone Marrow
Ovaries

Matroshka AstroRad Radiation Experiment (MARE)



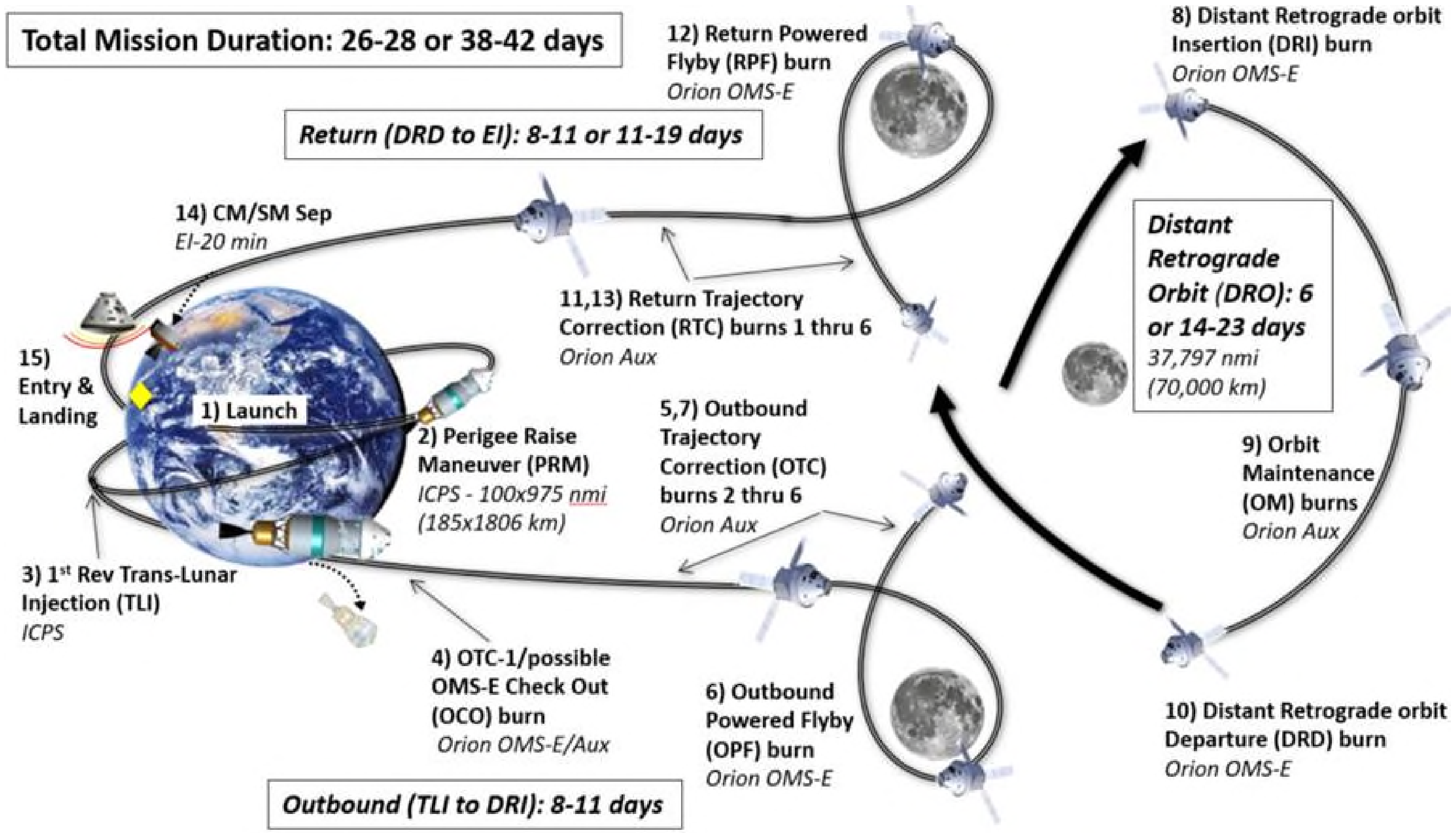
- Lockheed Martin invited feedback as part of Orion radiation protection efforts
- Israel Space Agency (ISA) and the German Aerospace Center (DLR) proposed MARE as an international science payload
- NASA approved the proposal in May 2017 and manifested it aboard the EM-1 flight.

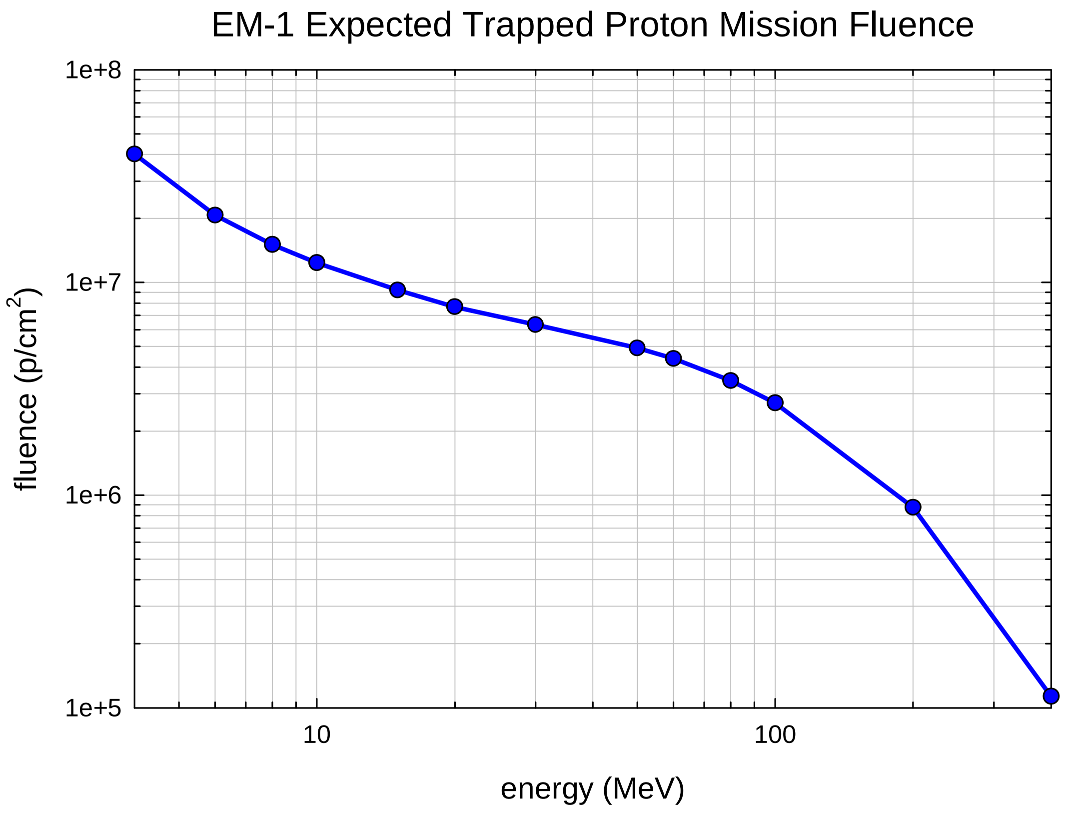
- MARE description
  - Two tissue-equivalent radiation phantoms inside the Orion cabin
  - Fitted with active and passive radiation detectors
  - One phantom fitted with the StemRad-manufactured AstroRad vest
- MARE is managed by DLR and ISA, with NASA as a co-PI
  - Lockheed Martin personnel co-located with Orion support development of MARE science objectives and efficient payload integration aboard the Orion vehicle



Exploration Mission 1 (EM-1)

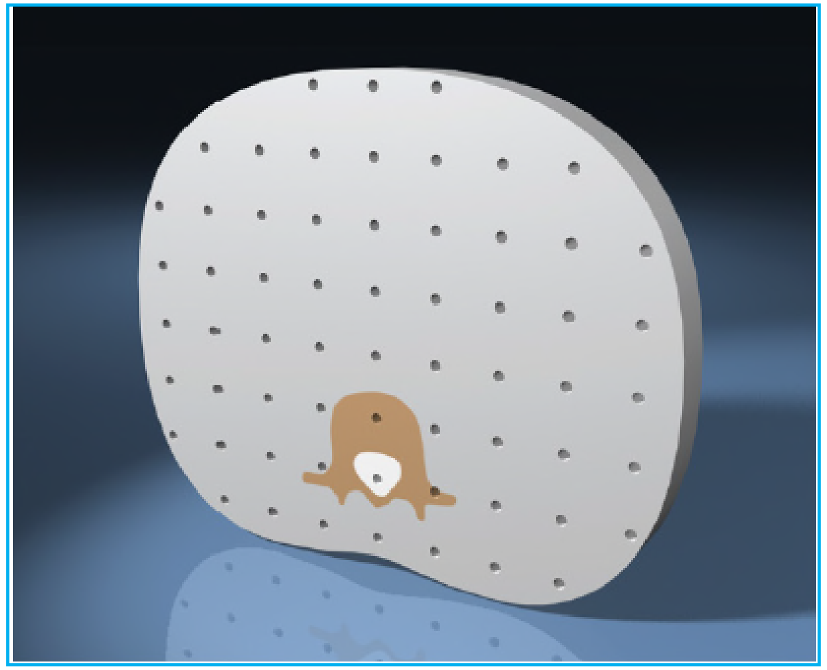
- **First Orion test flight beyond Earth orbit scheduled for 2020**
  - Uncrewed flight on Distant Retrograde Lunar Orbit (DRO)
  - Trapped protons, GCR, possibly SPE
  - Trapped proton exposure on the order of few mGy; CGR exposure ~0.5 mGy/day

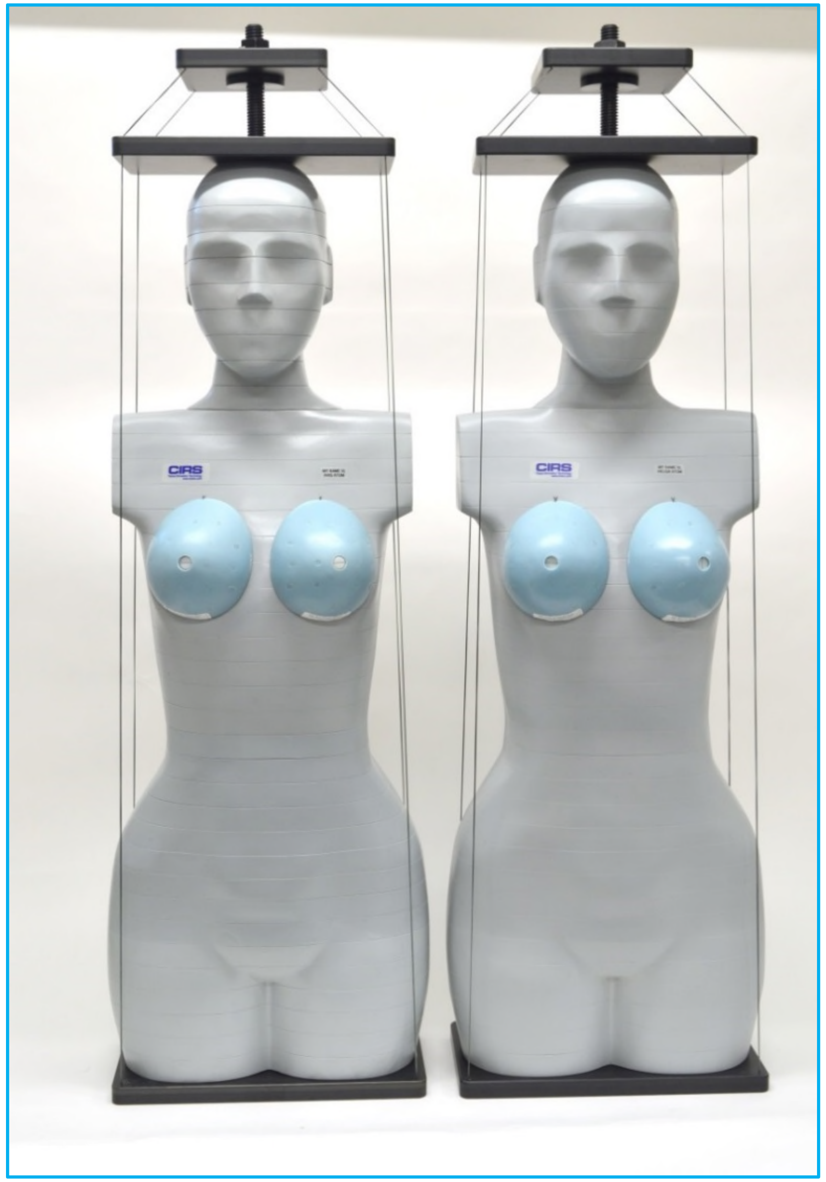


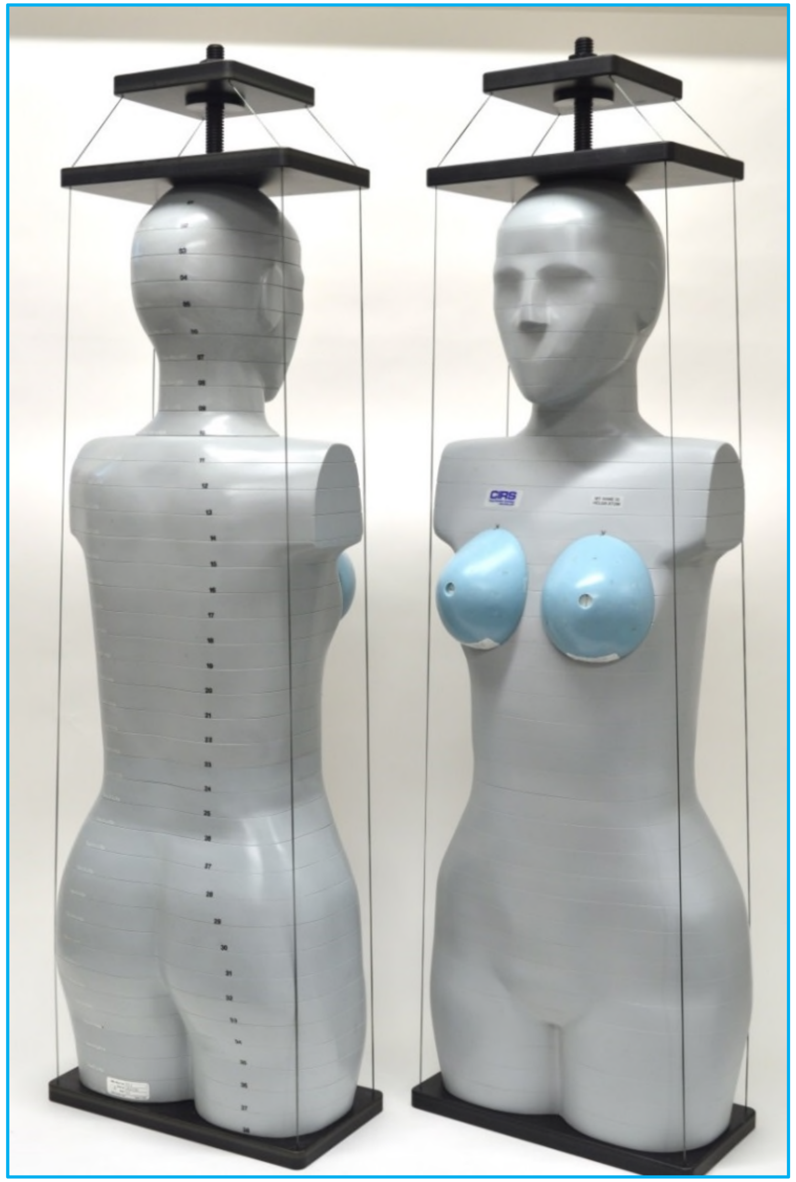


MARE: CIRS Phantoms

- **ATOM® 702 Female model**
  - Zohar 36.42 kg / Helga 36.48 kg
  - Tissue equivalent material
  - Artificial bone
  - 38 slices with TLD/OSLD holes



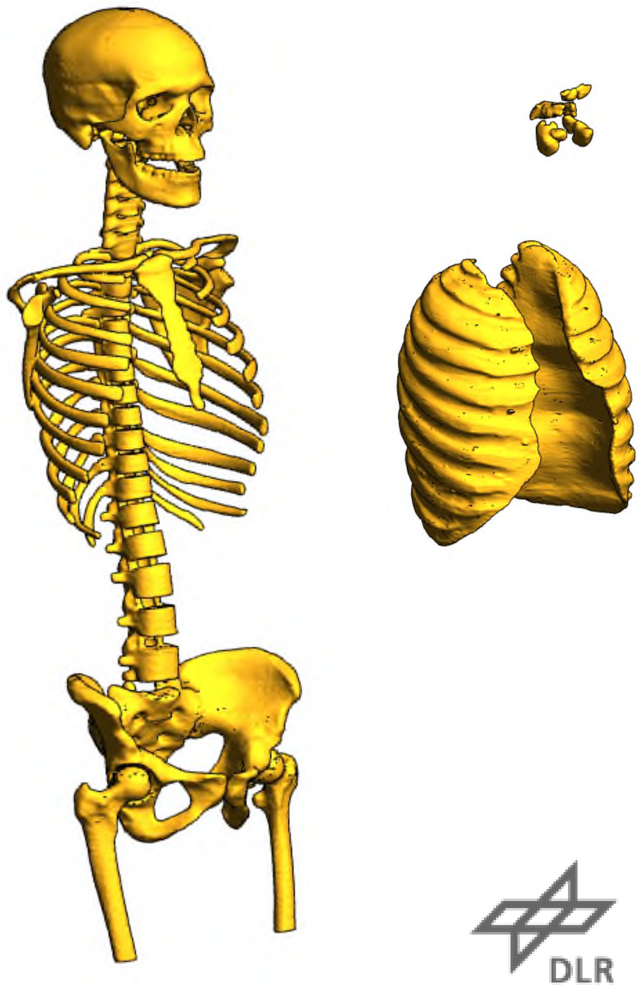


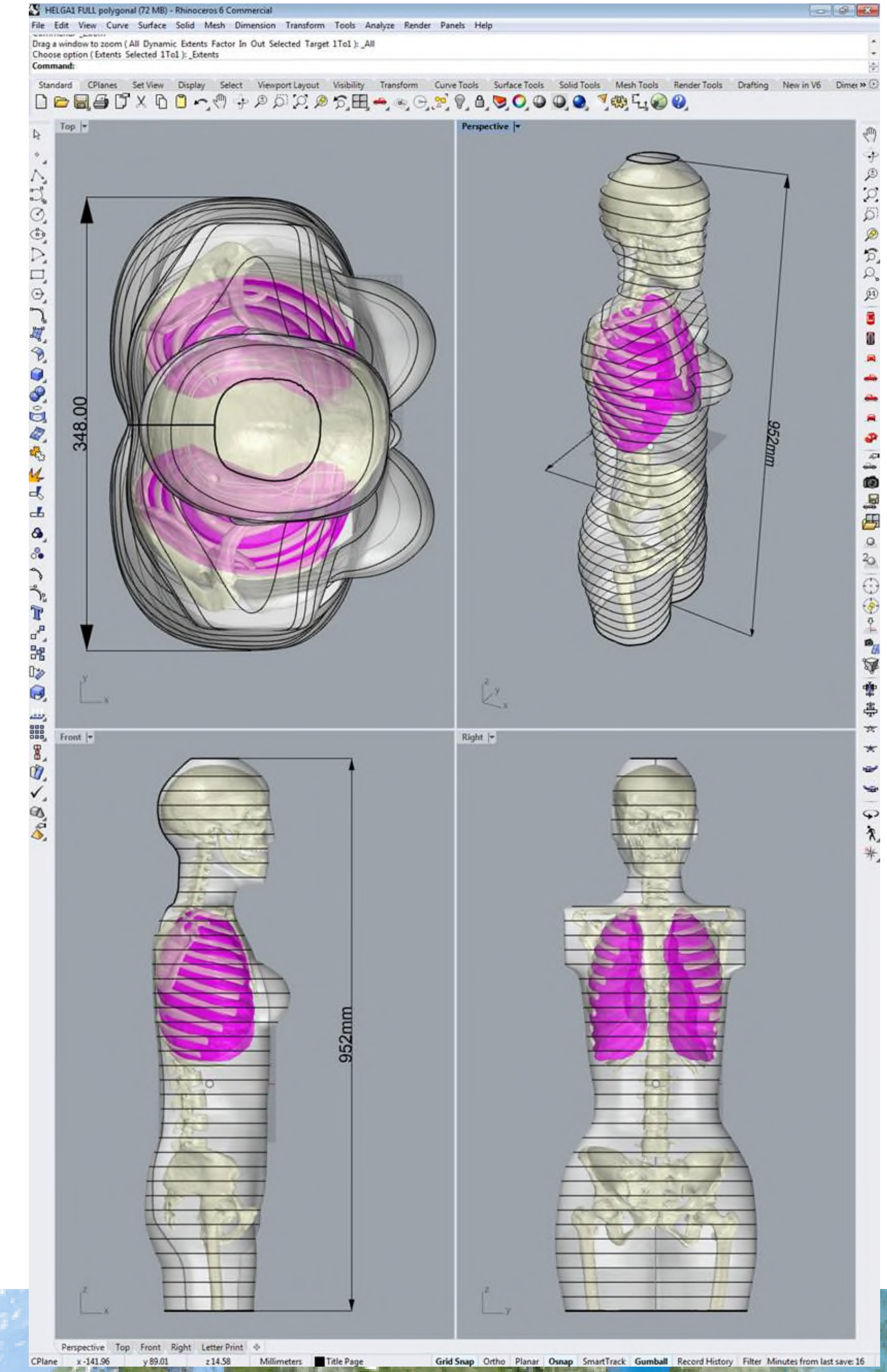


http://www.cirsinc.com/products/modality/33/atom-dosimetry-verification-phantoms

MARE: CIRS Phantoms Internal

- **CT scan performed on each phantom**
- **CT scan data are used to generate CAD models**
- **CAD models are used for AstroRad vest customization and radiation analysis**

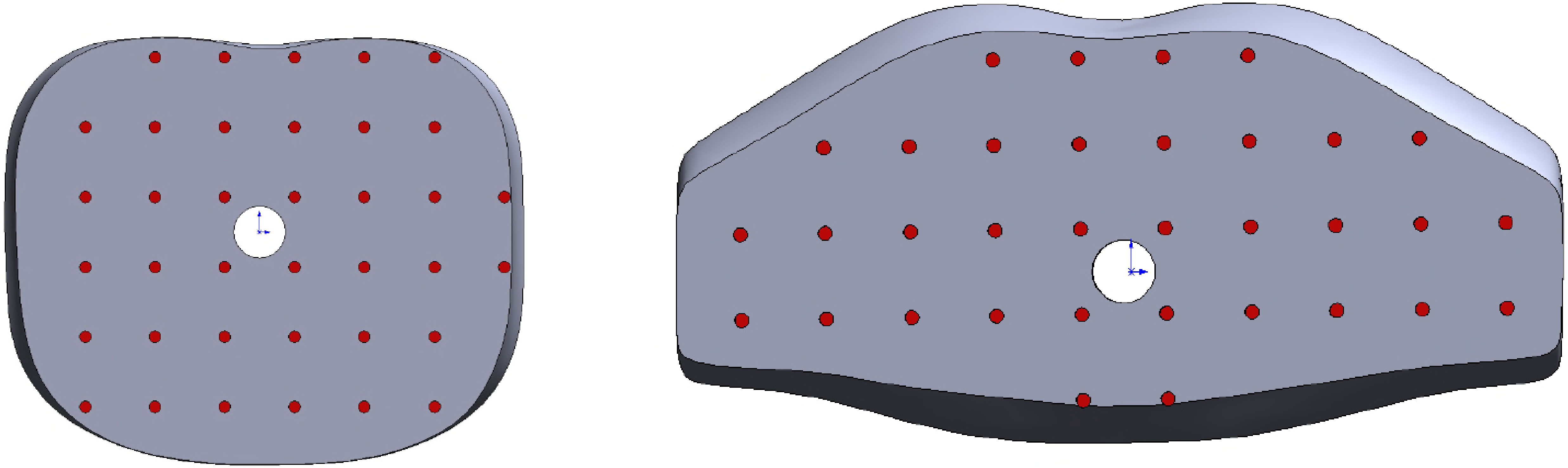




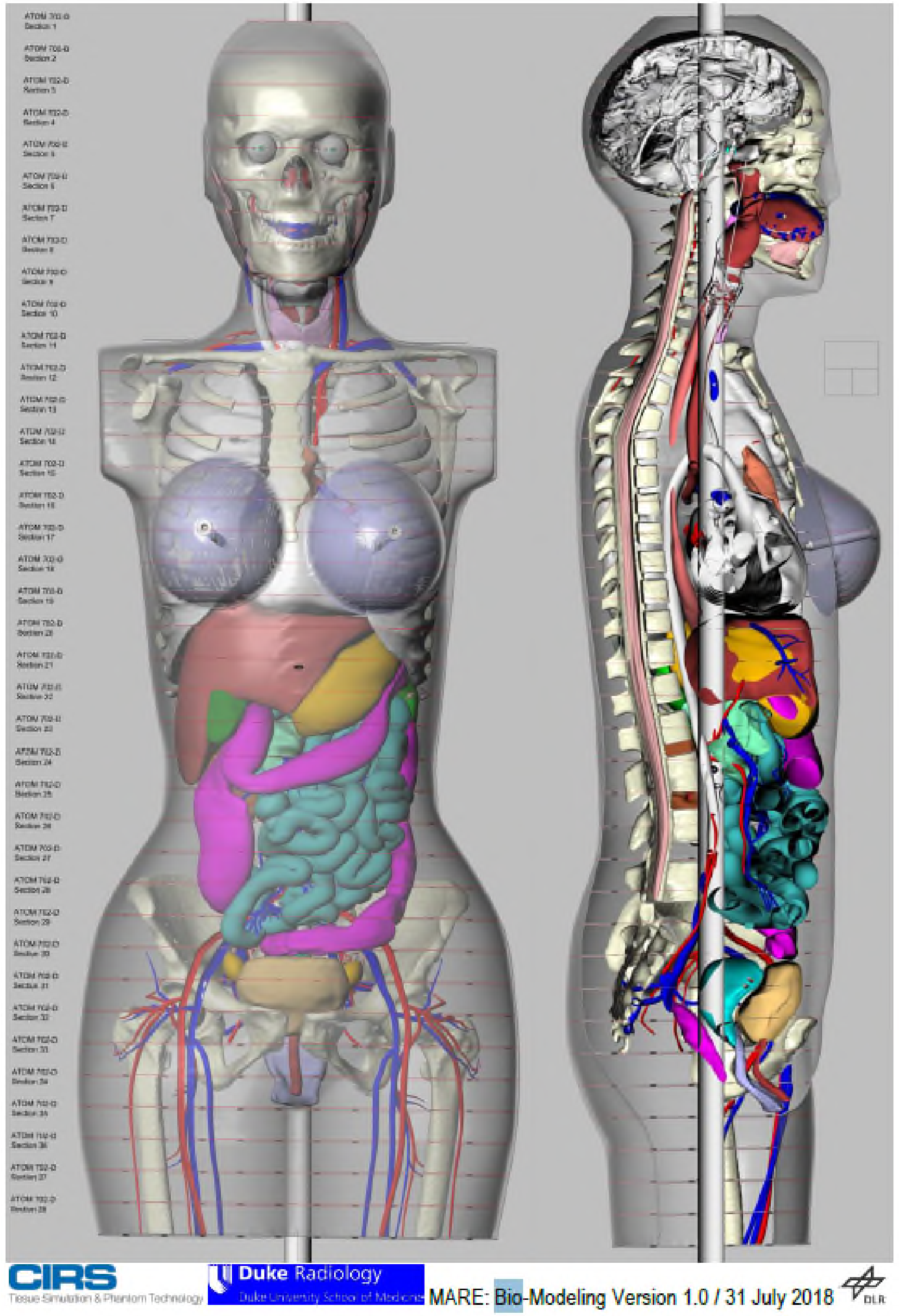
DLR

Internal Dose Mapping

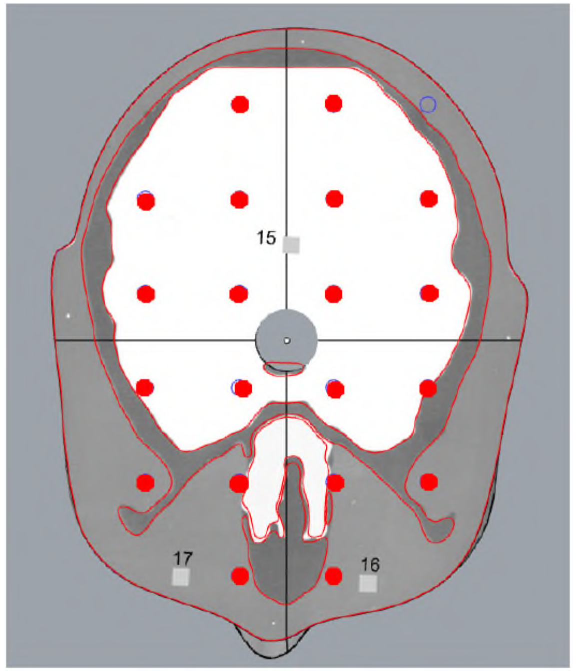
- **Passive dosimeters internal to the phantoms**
  - 3 cm x 3 cm grid
  - 6000 TLDs provided by DLR (750 measurement points/phantom, 4 TLDs/measurement point
  - 2000-3000 TLDs & OSLDs provided by NASA JSC (1000-1500 /phantom)

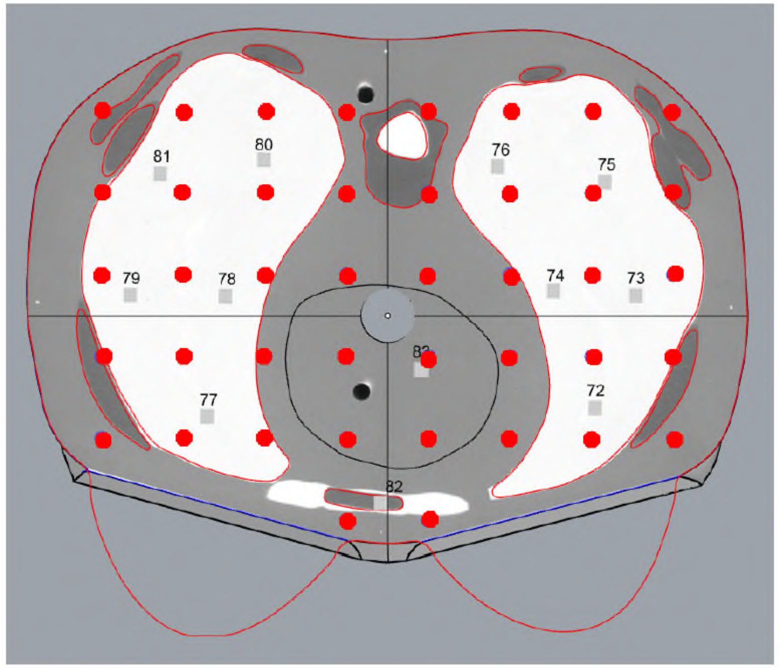


Bio-modeling



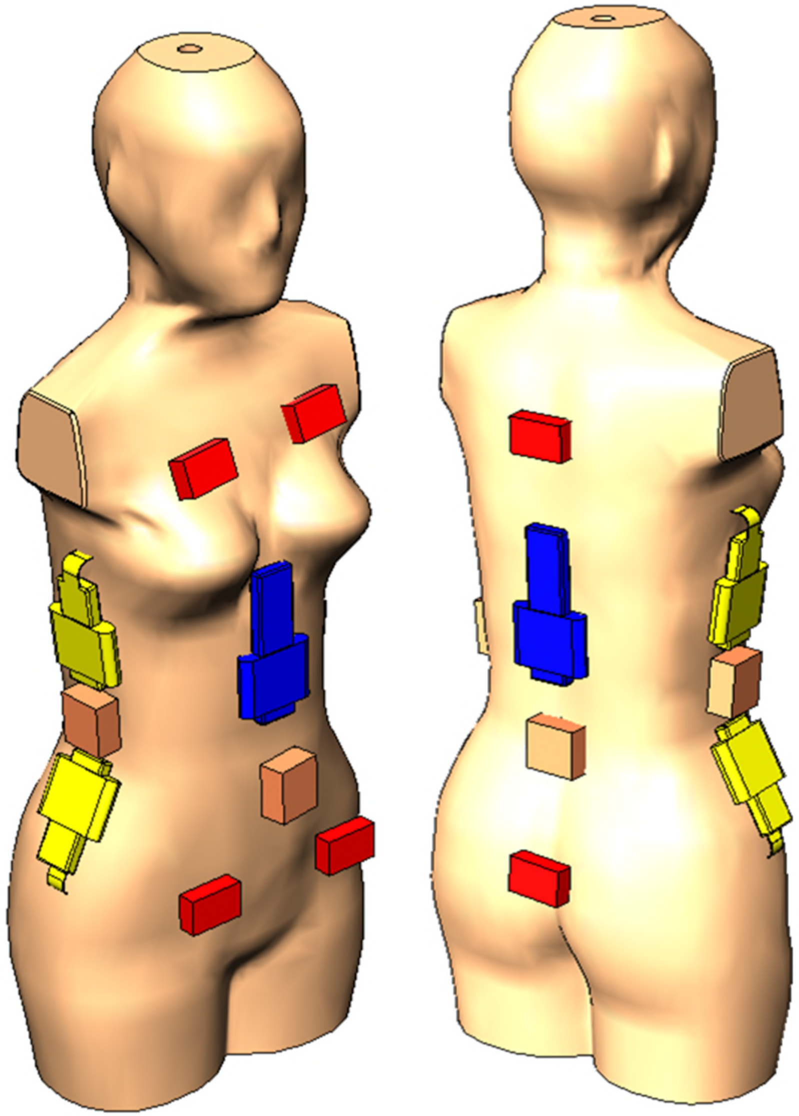
- **Radiation phantom materials**
  – soft tissue, bone, lung, brain, and breast (and void?)
- **CAD Bio-modeling**
  – Courtesy of W. Paul Segars, Ph.D., Duke University School of Medicine
  – Outlines organ shapes within the average soft tissue
  – Associates TLD grid locations with specific organs, allowing for organ dose calculations (analytic prediction & measurements)



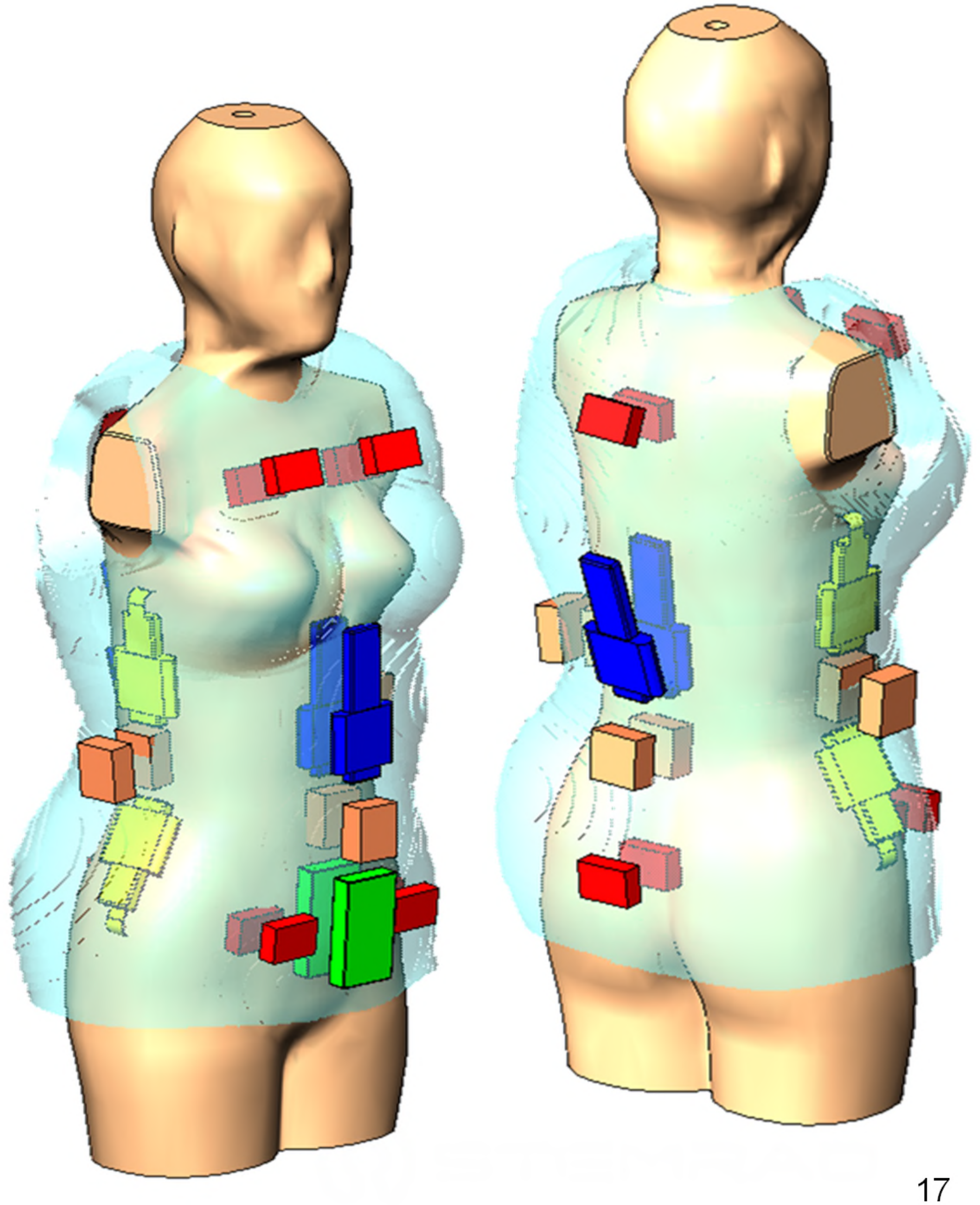


Additional Radiation Detectors

- Active detectors for surface (skin) and organ location measurements
- DOSIS Passive Dosimeter Packages (PDPs) for surface (skin) measurements
- PDPs provided by DLR for organ measurements (TLD + CR-39)



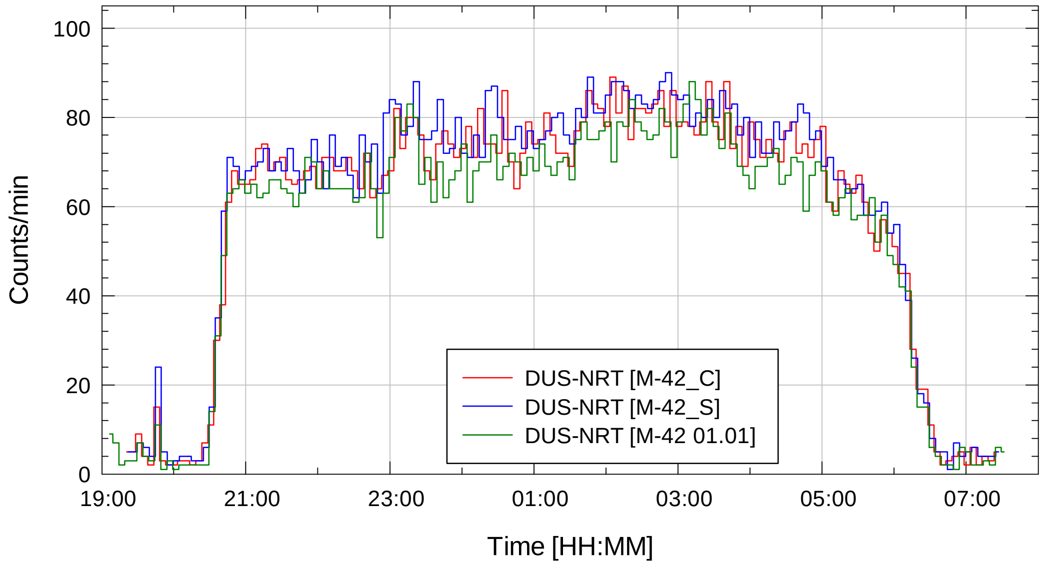
# Helga	Detector	Org	# Zohar
2	M-42 Compact	DLR	4
5	M-42 Split	DLR	5
6	CPAD	NASA	12
1	EAD-MU-O	ESA	2
4	DOSIS PDP	DLR	8
5	DLR PDP	DLR	5

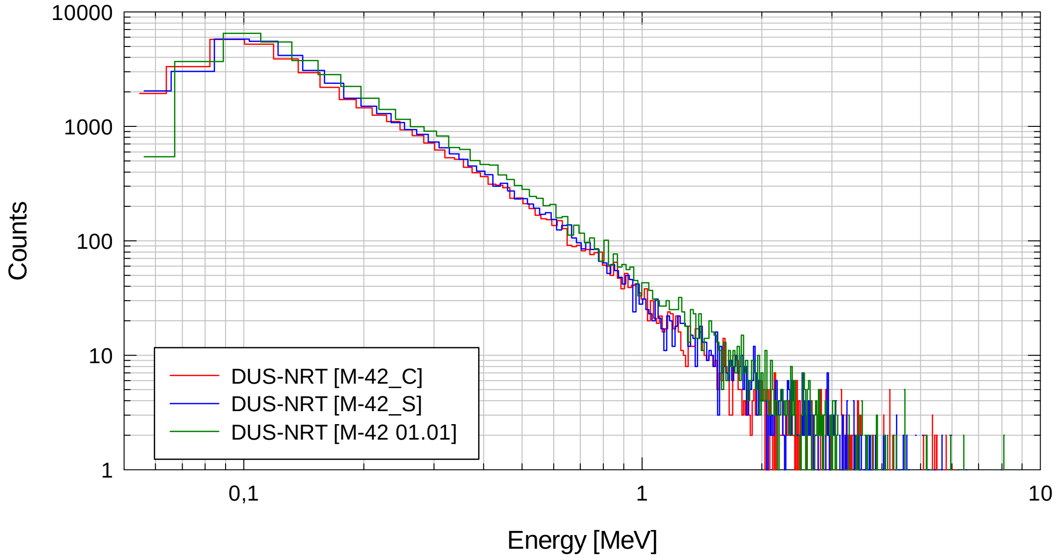


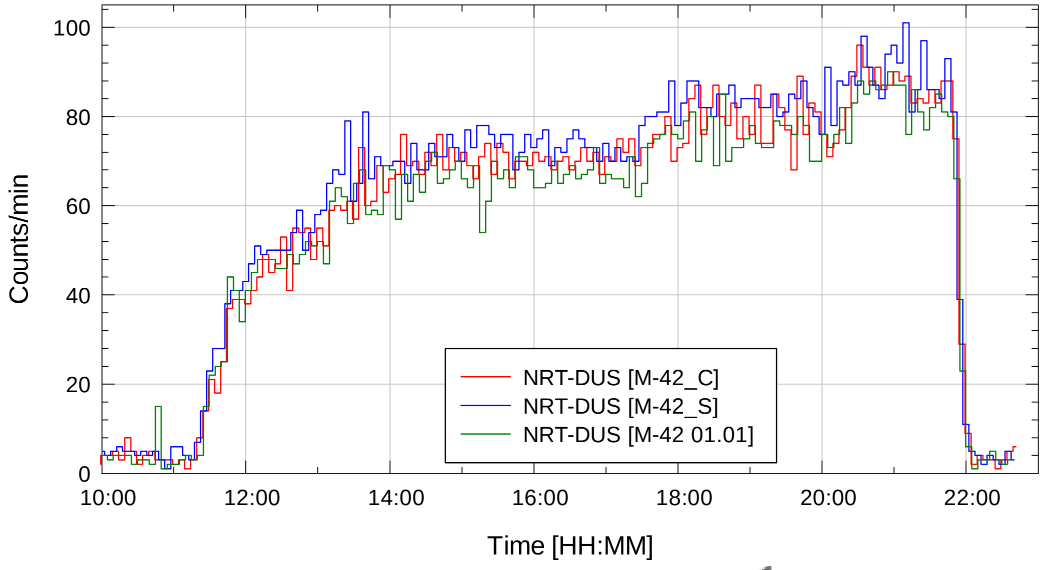
DLR M42

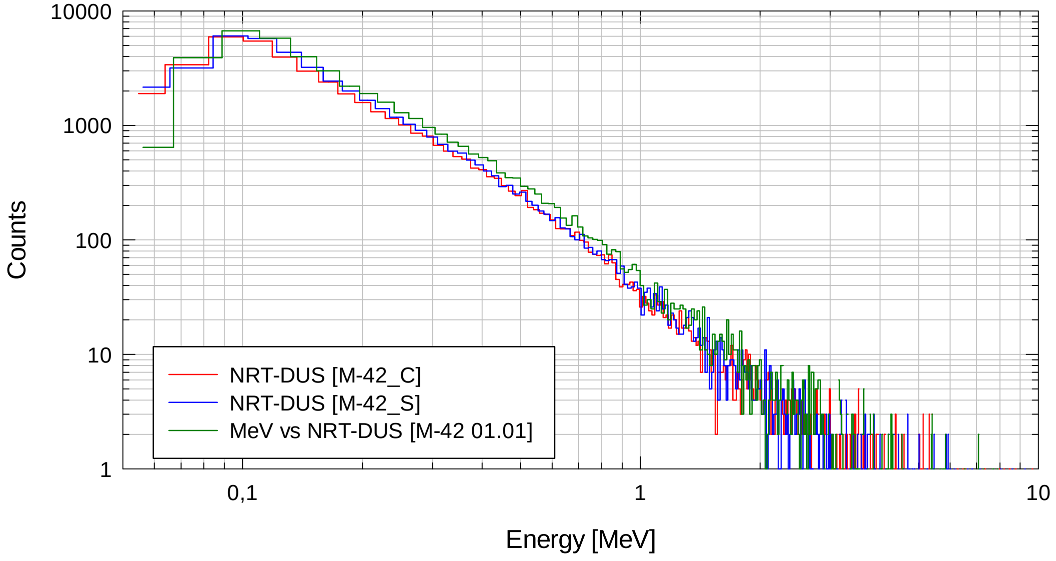
- **Silicon Detector**
- **Two versions**
  - Compact
  - Split
- **Autonomous operation**
  - Launch detection (accelerometer)
  - Run time > 42 days
- **Mass: 108-120 g**
- **1 cm^2 area, 300 μm thickness**
- **Energy range 0.06-20 MeV (Si)**
- **1024 channels**

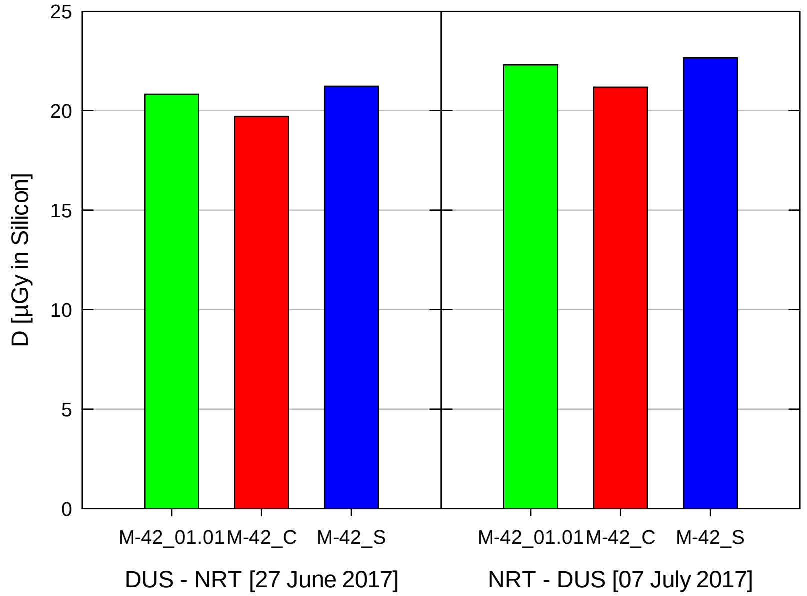
DLR M42 DUS-NRT and return







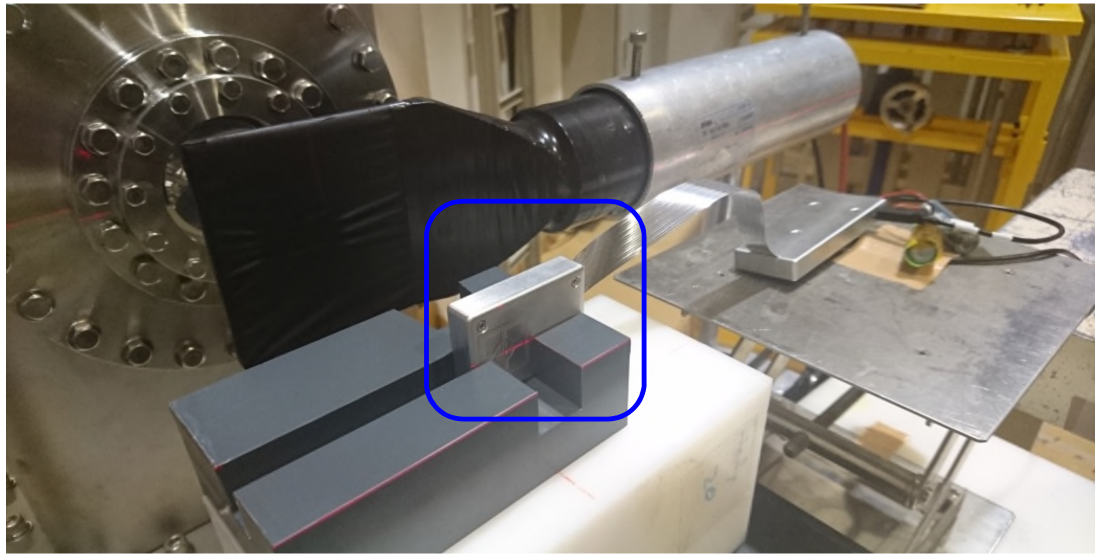


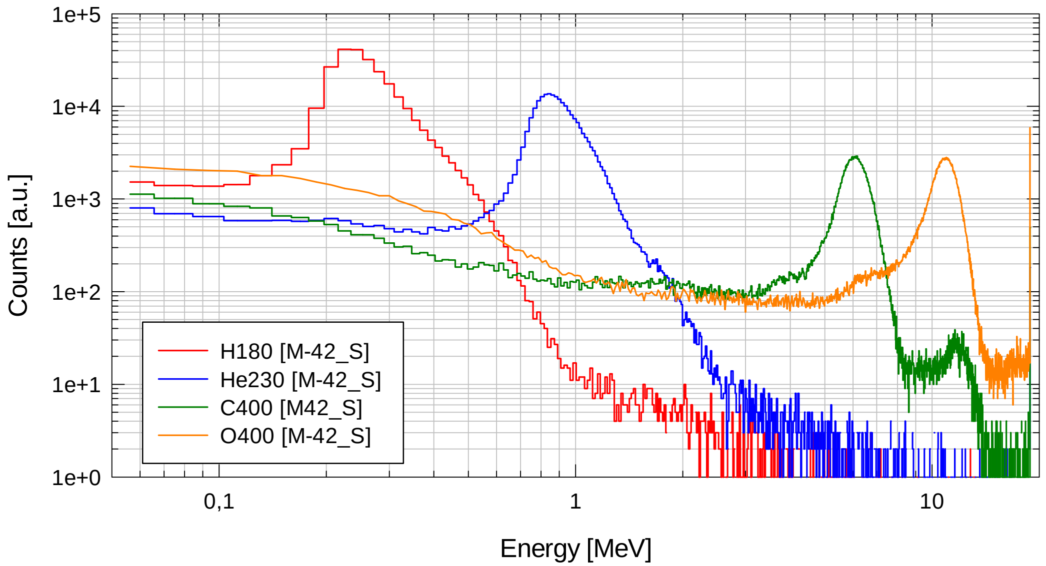


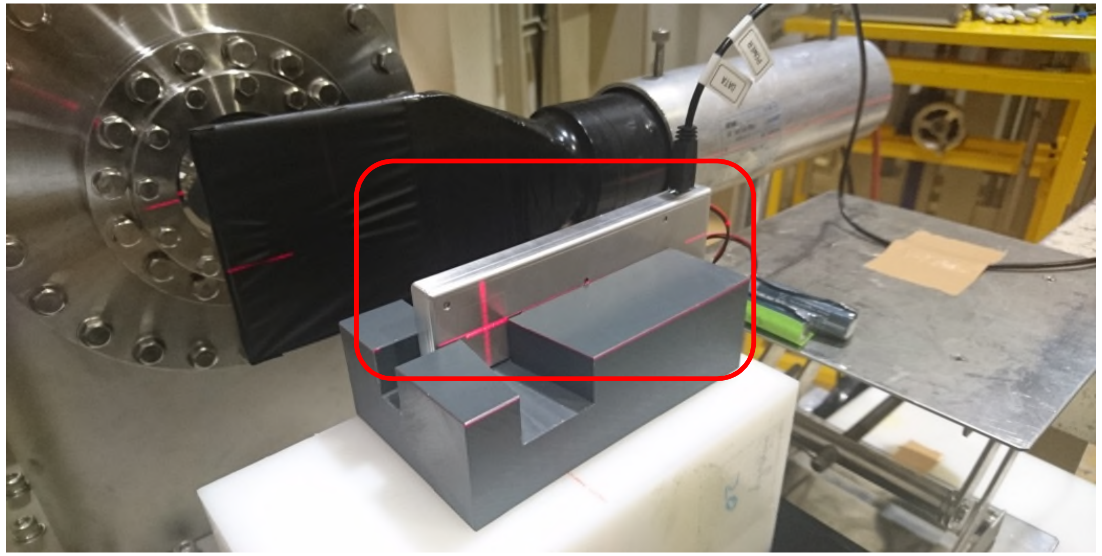
DUS-NRT: 20.56 ± 0.78 µGy in Si
NRT-DUS: 22.07 ± 0.77 µGy in Si

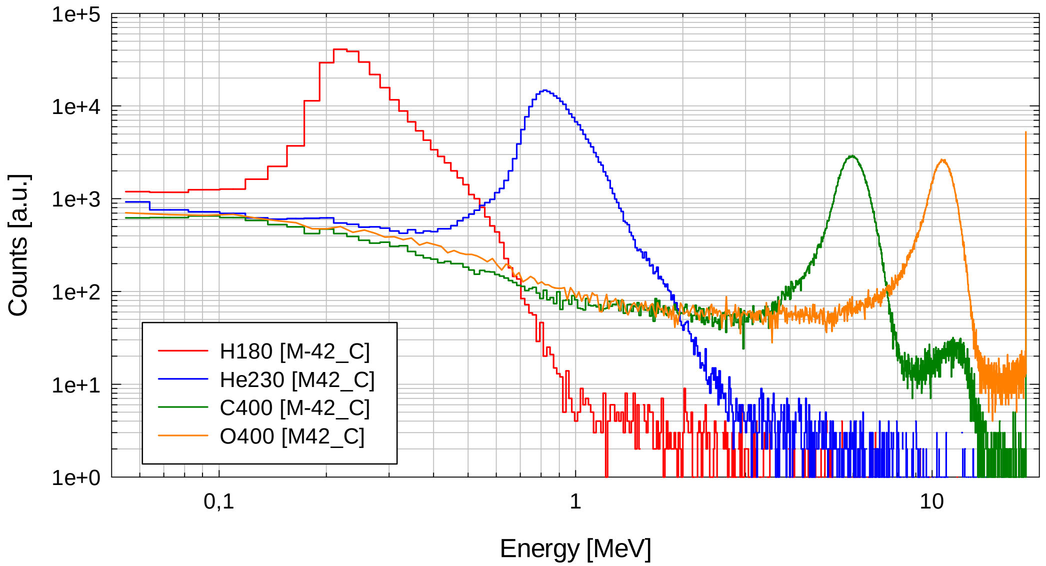
DLR M42 HIMAC Exposure

HIMAC Research Project 17H374



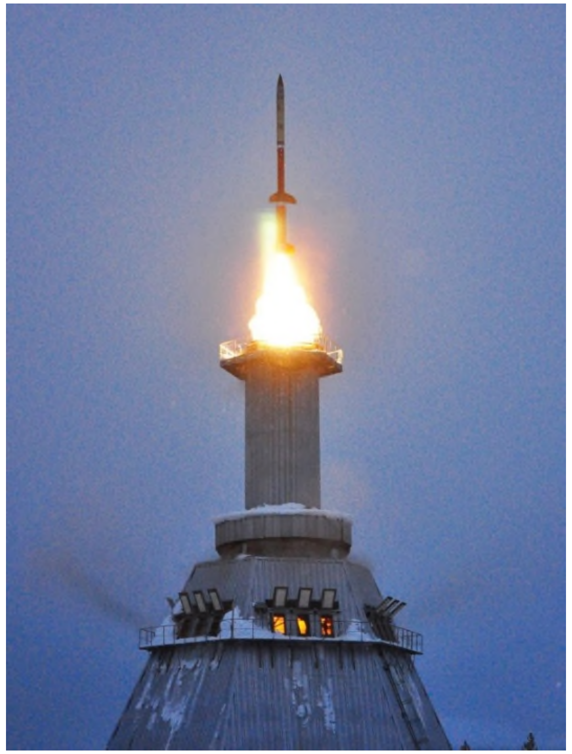


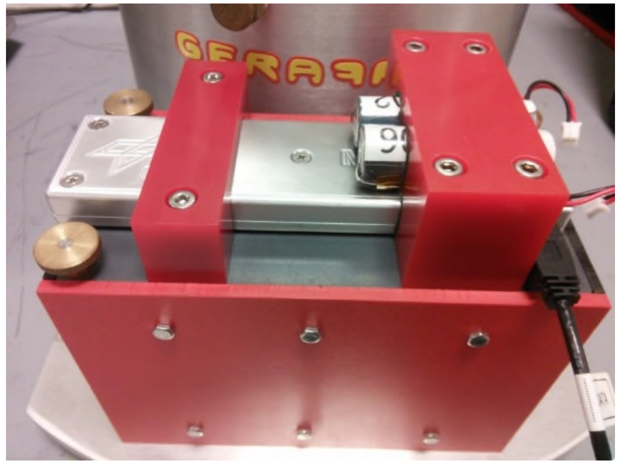


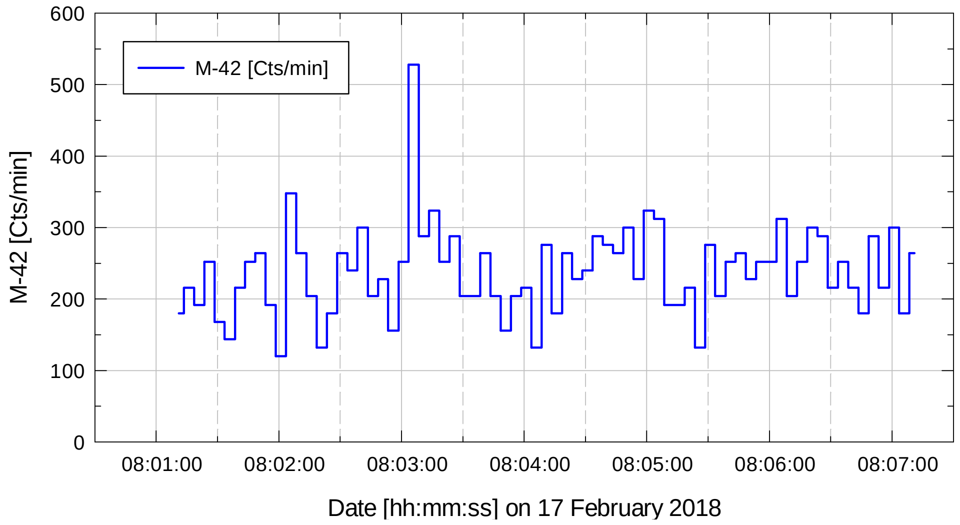


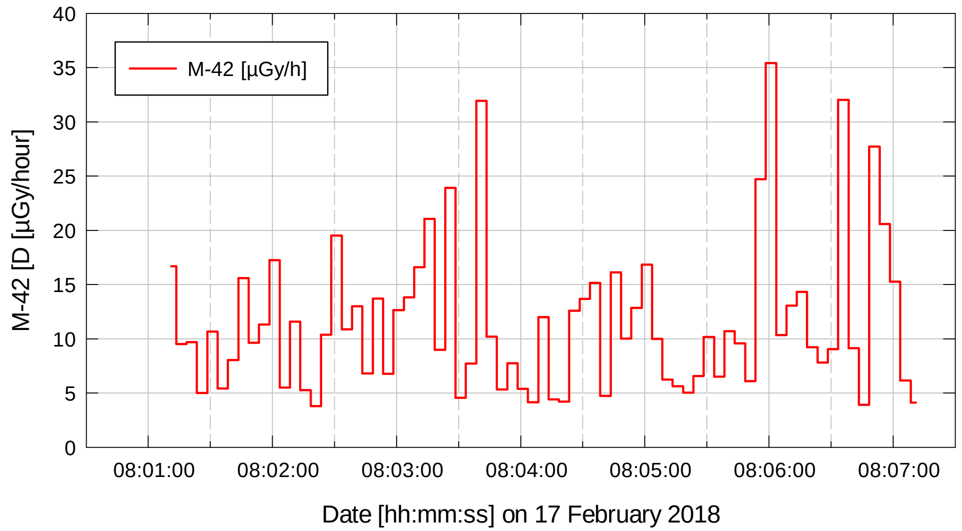
DLR M42 MAPHEUS testing

- **Load detector test performed aboard MAPHEUS DLR research rocket**
  - Max Altitude = 260 km
  - Flight Time = 14 min 10 s (6 min microgravity)
  - Launched from the European Space and Sounding Rocket Range, Kiruna, Sweden









NASA CPAD

- Crew Personal Active Detector
- ISS Tech Demo currently in progress
- Variable storage rate, no load detector needed
- Direct Ion Storage (Mirion Technologies)
- Mass <35 g, volume = 5.4 x 3.4 x 1.8 cm^3
- Battery life >10 months (configuration dependent)
- Display for crew information includes dose rate and cumulative dose
- Additional CPADs to be flown on EM-1 outside of MARE

ESA Active Dosimeter (EAD)

- **Provided by the European Space Agency**
  - Also referred to as EAD Mobile Unit – Orion (MU-O)
- **Based upon the existing ISS EAD MU**
  - ISS EAD system also includes docking station
  - MU-O requires upgraded battery lifetime
  - Additional instances of the EAD MU-O baselined to fly on Orion EM-1 outside of MARE
- **Mass 150 g, volume 6x10x3 cm^3**
- **Thin/Thick Silicon Detector**
- **Instadose®**
- **RadFET**

DOSIS 3D PDP

- **Dose Distribution Inside the International Space Station - 3D**
  - DLR lead effort to dose map all the ISS segments (2012 – 2018)
  - Passive Dosimeter Package (PDP) includes TLDs + OSLDs + CR-39 PNTDs
  - Large international participation includes:
    - 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
    - NASA JSC, Houston, TX, USA

Path Forward

- **International collaboration framework**
- **MARE System Requirements Review (SRR)**
  - Validation of design requirements
- **Continued design, payload integration, and requirement verification efforts**
  - Exploring addition of detectors from the Canadian Space Agency / BTI, and Thessaloniki University Greece
  - Safety certifications
- **Dose projections refinement**
- **Late stow vehicle installation**
  - Minimize ground exposure
- **EM-1 Flight**
- **Post-flight data processing, consolidation and publication**
  - AstroRad vest improvements

Conclusion

- **Orion is the first Exploration architecture component**
  – MARE is among the first Orion payloads
- **International collaboration is critical to successful space exploration**
- **MARE as example of upcoming science research opportunities**

Our goal is to improve astronaut safety and enable Exploration