Radiation Protection in Spaceflight

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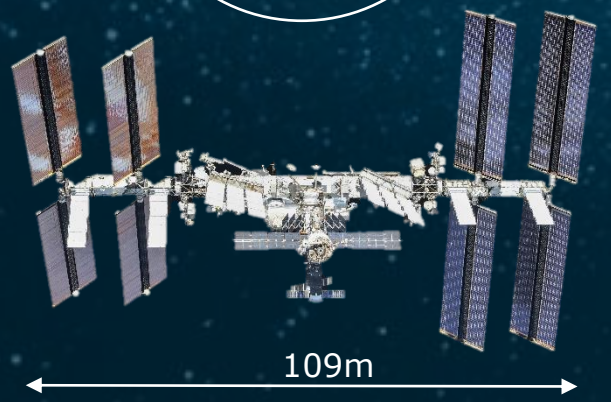
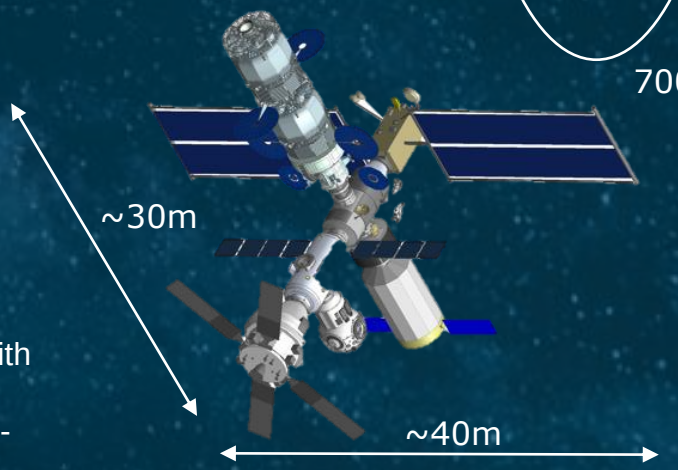
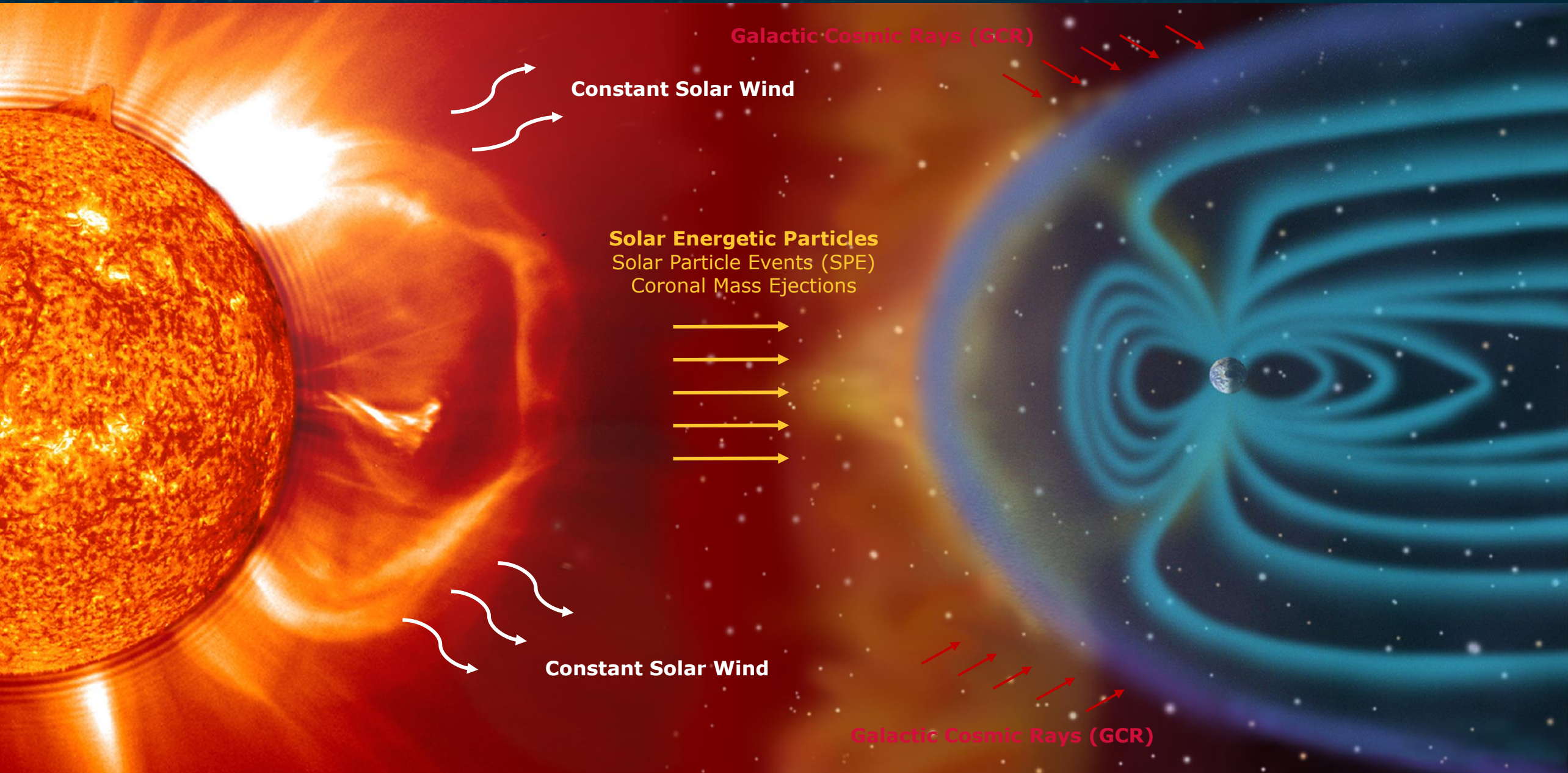
Challenges of spaceflight: LEO and Beyond

Low Earth Orbit - ISS: Known medical risks, Constant communication, Access to Earth, Minimum autonomy		Moon – Gateway & surface: Mostly known medical risks (short duration), Small delay in communication, Access to Earth within days, Greater autonomy required
6-8 Crewmembers		2-4 Crewmembers
6 month crew missions		30-90 day crew missions
~338m³ habitable volume		~25-25m³ habitable volume + 11m³ Orion
Earth LEO of 90 min.		Moon NRHO of 7days, 380000km from Earth
Emergency return within hours		Emergency return up to 10 days
Real-time audio/video		Constant communication with ~5 sec. delays Difficult remote guiding/tele-operating

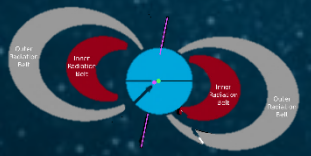




Space Radiation Environment



Spaceflight – related radiation exposures

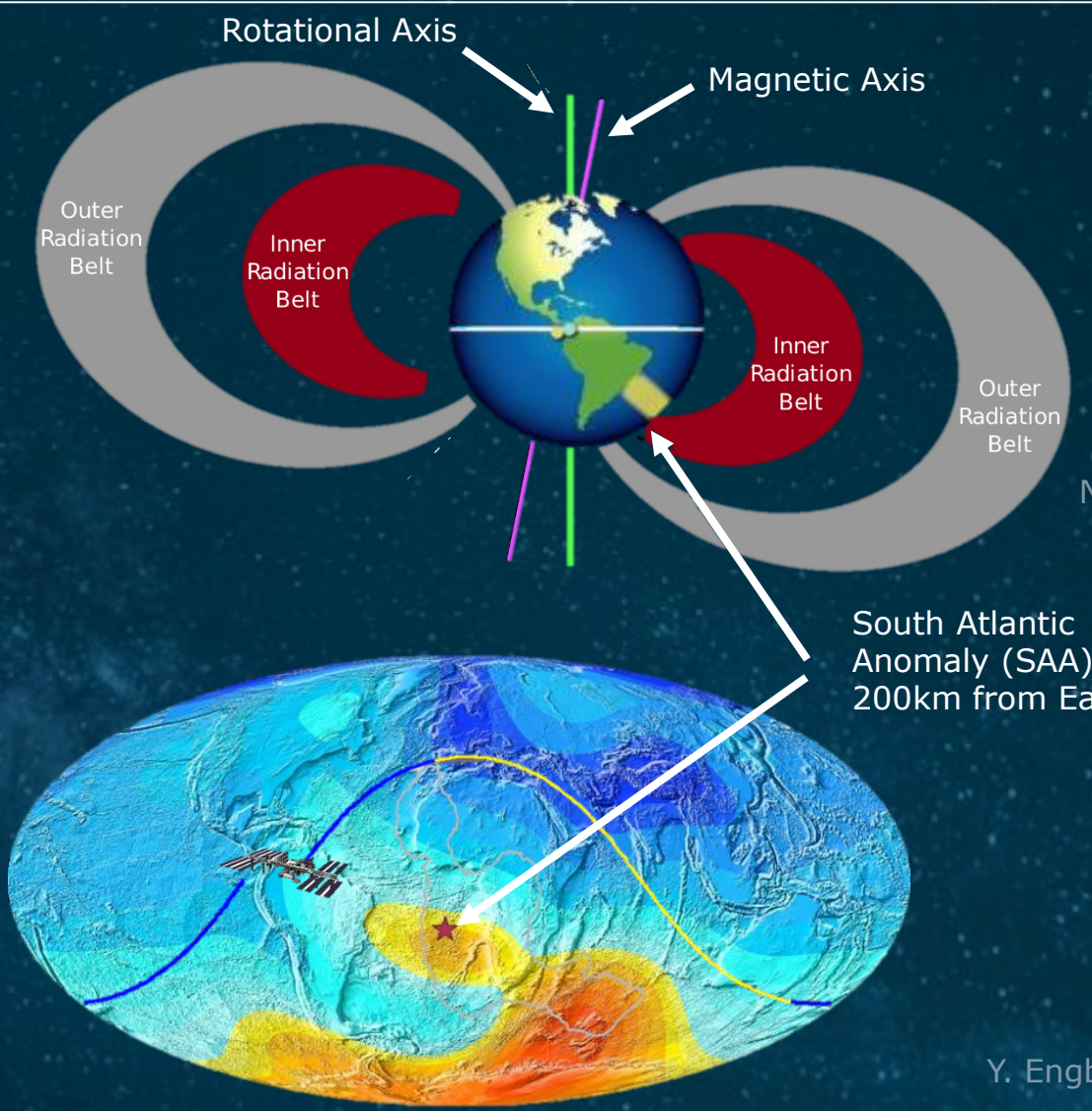
Radiation sources	Primary particles	Secondary particles
 Galactic Cosmic rays (GCR)	87% Protons 12% Helium 1% Heavy nuclei 100 MeV – 100 GeV	Neutrons Protons Electrons X-rays Gamma rays Recoil heavy nuclei
 Earth radiation belts	Electrons & Protons 1k – 12k km 1 – 5 MeV 13k – 60k km 10 – 100 MeV	
 Solar Particle Events (SPE)	92% Protons 6% Helium 2% Heavy nuclei keV – 100 MeV	

Barratt, Baker, Pool, 2019 (modified)

Spaceflight – radiation exposure levels

Event	Radiation dose level
ISS skin dose solar max.	0.5 mSv / day
ISS skin dose solar min.	1 mSv / day
Shuttle average mission skin dose	~4.3 mSv / day
EVA exposure with passes through SAA	4.5 mSv / event
Skin dose during 1989 SPE (Shuttle, no EVA)	10 mSv / event
Apollo 14 (highest skin dose)	14 mSv / mission
Mir crewmember dose to BFO during 1989 magnetic storm	30 mSv / event
Skylab 4 (highest skin dose)	178 mSv / mission

Barratt, Baker, Pool, 2019 (modified)

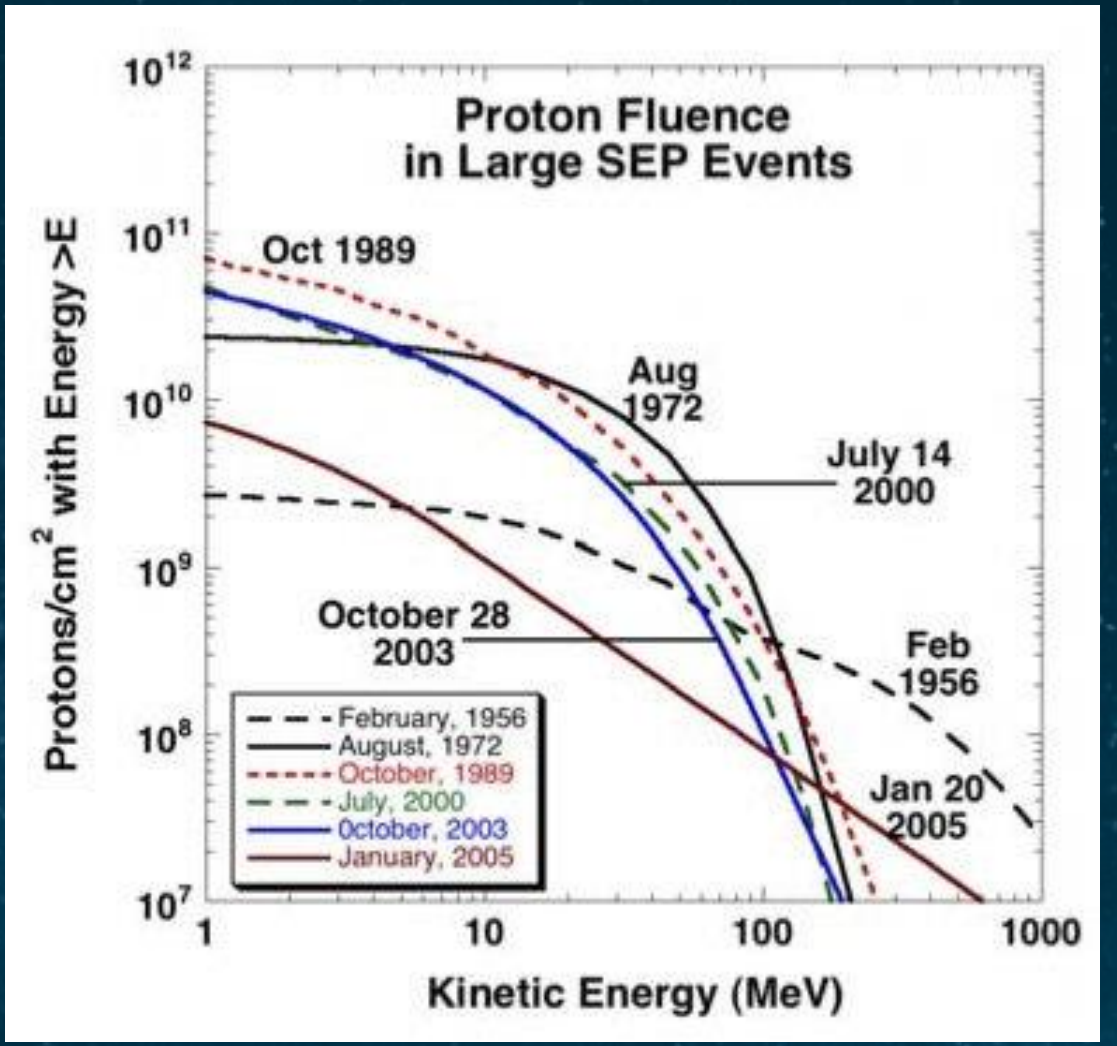


Y. Engbers

Radiation exposures in LEO & BLEO

Galactic Cosmic Rays (GCR)	Trapped Radiation in radiation Belts	Solar Particle Events (SPE)
Dependent on Solar Cycle and shielding		Dependent on shielding and solar activity
ISS & exploration missions	ISS: intermittent whole body exposure to low doses	ISS: protection by geomagnetic field
Chronic whole body exposure to low doses	Exploration: Short whole body exposure	Exploration missions: risk of acute whole body exposure to high doses
• Single energetic particles • Secondary particles • 24/7 exposure	• SAA important for dose accumulated on ISS • Belts traversed during exploration	• Mostly protons • High dose rates possible • Dangerous with insufficient shielding (EVA)

Hellweg et al., 2020 (modified)



Bamford, 2017; after Nelson, 2016 and Wilson, 1997

Radiation - induced effects

Deterministic

- Severity dependent ("determined") on the dose
- Effect only when exposure exceeded threshold
- Damage of large amount of cells
- Usually short latency

- Acute radiation syndrome
- Chronic post-radiation syndrome (cataract, radiation dermatitis)
- Sterility

NASA

Stochastic

- Probability increases with the dose (not the severity!)
- No "safe" threshold
- Damage of single cell can be enough to cause effect
- Manifestation delayed (typically years)

- Somatic mutation (cancer)
- Germline mutation (inherited genetic disease)
- Degenerative/chronic diseases

- Real-time dosimetry
- Storm shelter & protocols on board
- Limited medical care on board

- Real-time dosimetry
- Radiation Risk Assessment

Radiation Protection for human spaceflight

Short-term dose limits to prevent deterministic effects

Consensus dose limits for BFO adopted by MMOP	
Organ specific equivalent dose limits for BFO	
30 Days	0.25 Sv
Annual	0.50 Sv

ESA equivalent dose limits	
Organ specific equivalent dose limits for BFO | Eye | Skin	
30 Days	0.25 | 0.5 | 1.5 Sv
Annual	0.50 | 1 | 3 Sv

After Straube et al., 2010

NASA

Career dose limit / threshold risk estimate to prevent stochastic effect

- ESA career limit of 1 Sv (ICRP 60)
- RSA - 10% excess total radiation risk (cancer and non-cancer)
- NASA - 3% probability of lifetime excess cancer mortality risk (REID) – NASA Space Radiation Cancer Risk (NSCR) Model

REID indicates that 3 people per 100 may die from cancer due to exposure, but it doesn't tell, if there are other, non-cancer threats, and it doesn't give recommendations whether it's worth to take the risk and if so, who and when will die

Age at exposure	Females	Males
30	0.6	0.78
40	0.7	0.88
50	0.82	1.0
60	0.98	1.17

Radiation protection beyond Low Earth Orbit

Redefining New Standards for Deep Space Exploration

ICRP Task Group 115
Risk and Dose Assessment for Radiological Protection of Astronauts

Recommendations by The Radiation Health Working Group (RHWG) to the Multilateral Medical Operations Panel (MMOP)

Adaptations of the RHWG recommendations by the MMOP

Gateway Crew Health and Performance requirements

Operational Radiation Protection for spaceflight

Best

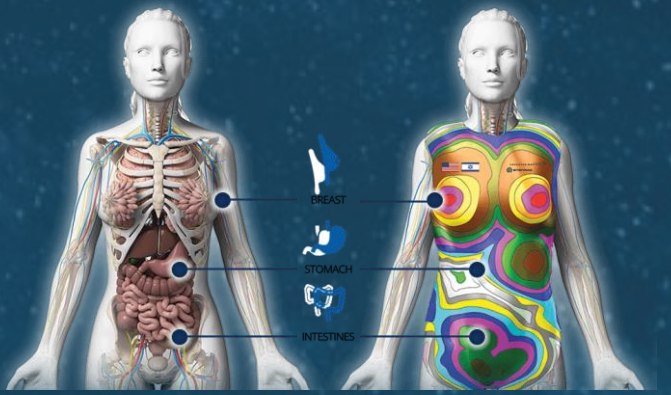
- Liquid H_2
- Liquid CH_4
- Polyethylene CH_2
- H_2O
- Aluminium Al
- Lead Pb

Worse

Is shielding a solution?

Perseo Water Vest
Thales Group

AstroRad Polymer Vest, StemRad



Science for & in Space: Radiation Research Opportunities

On the Ground

Investigations into Biological Effects of Radiation

- AO IBER (GSI)
- CORA IBER (GANIL, AGOR KVI-CART, HIT, UPTD, TIFPA)
- GSI-FAIR – opening soon

On the International Space Station

Announcement of Opportunities

- DOSIS 3D – environmental radiation monitoring
- LUX in space - to study DDR under microG with the use of UV source for DNA damage
- Exobiology facility - externally to the ISS on the Bartolomeo platform to study the effects of radiation exposure on biological and chemical samples

On the Moon Orbit, Gateway Station and beyond

Artemis -I

- 5 ESA Active Dosimeters (EADs) measuring radiation environment inside ORION spacecraft during uncrewed mission around the Moon

Gateway

- Research Announcement for Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) Interdisciplinary Science Teams – in cooperation with NASA
- Research Announcement for European Radiation Sensor Array (ERSA) International Science Team – research announcement opening soon
- Internal Dosimeter Array (IDA) - research announcement opening soon

Moon

- ESA's European Large Logistics Lander (first payloads selected in 2022)

Mars

- Earth Return Orbiter (ERO) (payload concept under development)

Thank you