ISPCS
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Exploration missions and radiation

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... Humans are in space ...
From ISS to …
Limiting factors for long duration human exploration missions

**Microgravity**
- Brain functions
- Cardiovascular system
- Weight-bearing structures
- Immunological response

**Psycho-social**
- Isolation, confinement and separation from Earth
- Loss of privacy, social tensions, psychosocial stressors
- Different nationalities, religious, social and cultural ideals

**Radiation environment**
- Short term radiation effects (deterministic)
- Long term radiation effects (stochastic)
Radiation – we can not taste, smell, see it (*)

http://www.esa.int/spaceinvideos/Videos/2017/09/Solar_events © SOHO (ESA & NASA)
Radiation – we can measure it

Cologne, Germany

Airplane

Turku, Finland

International Space Station
Finland (Turku)

Data:
Airplane (DUS-NRT)

Data:

- Germany
- Finland
- Airplane

Particle hits in 300 seconds

Time (hours)
International Space Station

Data:
RADIATION  WHERE DOES IT COME FROM?
The Space Radiation Environment

SUN – Solar Particle Events (SPE) (*) just seen before
⇒ Protons (in dependence of the solar cycle)

Galactic Cosmic Radiation (GCR)
⇒ Ions from protons to iron

Trapped Radiation Belts (Van Allen Belts)
⇒ Low energy protons and electrons

→ Beyond Low Earth Orbit: GCR and SPE / no protection from the Earth magnetic field / much harsher environment for exploration
RADIATION TO MEASURE IT
RADIATION: HISTORY II – RADIATION DETECTORS IN SPACE

Now: The International Space Station
The ISS: **passive** and **active** radiation detectors – area monitors
The ISS: Personal (passive) radiation detectors
The ISS: Personal (passive) radiation detectors

The ISS and beyond: Personal (active) radiation detectors
The ISS and beyond: Personal (active) radiation detectors
Radiation Risk

Personal (passive and active) dosimeters only measure the dose at the surface of the body.

Organs have different sensitivity to radiation.

→ To determine baseline quantities for radiation risk estimations one should measure directly inside the radio-sensitive organs.

→ To measure inside organs – this can only be achieved with anthropomorphic phantoms.
RADIATION: Phantoms....
MATROSHKA A first step on board the ISS

More than 6,000 passive radiation detectors

Over 1,600 measurements sites in a regular 2.5 cm x/y/z grid

Seven active radiation detectors

http://www.fp7-hamlet.eu
MATROSHKA four phases on board the ISS

- **MTR-1** (2004–05) 539 days
- **MTR-2A** (2006) 337 days
- **MTR-2B** (2007–09) 518 days
- **MTR-2 KIBO** (2010–11) 310 days
MATROSHKA On orbit work
MATROSHKA The dose inside the body I
MATROSHKA The dose inside the body II


Dose (mGy/d)

Data:
RADIATION: BACK TO THE MOON

© NASA

© ESA / Paolo Nespoli
Radiation – we can measure it

- 224 Gm
  ~ 0.1 µSv/h × 1

- 420 km
  ~ 0.2 µSv/h × 2

- 10 km
  ~ 4 µSv/h × 40

- 3 km
  ~ 25 µSv/h × 250

- 50 m
  ~ 0.1 µSv/h × 1
Radiation – we can measure it: and it is way harsher in free space

- MSL/RAD: ~ 26 µSv/h × 260
- MSL/RAD: ~ 77 µSv/h × 770
- DOSIS 3D: ~ 25 µSv/h × 250
- ~ 4 µSv/h × 40
- ~ 0.2 µSv/h × 2
- ~ 0.1 µSv/h × 1
Deep Space Gateway
ORION Exploration Mission-1 (EM-1) Mission

https://www.nasa.gov/exploration/systems/orion/index.html
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)

MARE will expose two female phantoms / one with radiation protection vest to the harsh radiation environment in lunar orbit and determine all relevant radiation protection quantities as well as the protection properties of the AstoRad vest

Accepted by NASA and manifested for flight in May 2017
ORION EM-1 MATROSHKA AstroRad Radiation Experiment

- 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
ORION EM-1 MATROSHKA AstroRad Radiation Experiment

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

The MARE team includes Lockheed Martin personnel collocated with the Orion program for efficient payload integration and spacecraft shielding analysis

Enabling Orion as a platform for future experiments

International endeavor and opportunity for radiation protection for exploration
ORION EM-1 MATROSHKA AstroRad Radiation Experiment

- International endeavor for radiation protection for exploration

Razvan Gaza¹, Hesham Hussein¹, David Murrow¹, Chirag Patel¹, Gideon Waterman², Oren Milstein²,
¹Lockheed Martin Corporation, USA
²StemRad Ltd, Israel
Summary

- Space is a harsh environment – and even harsher for exploration

- Radiation and the radiation load on humans are one of the main concerns for exploration missions

- Technologies have been and are under development to determine the relevant exposure conditions

- Phantoms (as for ORION EM-1) offer a perfect opportunity to determine the dose in critical organs outside Low Earth Orbit

- New technologies (as the AstroRad vest) shall enable a safer travel in space

- The future is wide open
Particle hits → Dose equivalent

Cumulative dose equivalent for a 12 hour time period.

Data:
# MATROSHKA The final results

<table>
<thead>
<tr>
<th></th>
<th>MTR-1</th>
<th>MTR-2A</th>
<th>MTR-2B</th>
</tr>
</thead>
<tbody>
<tr>
<td>dose</td>
<td>700 µSv/d</td>
<td>530 µSv/d</td>
<td>570 µSv/d</td>
</tr>
</tbody>
</table>
# Radiation On Earth

<table>
<thead>
<tr>
<th>Source</th>
<th>Annual average dose (mSv)</th>
<th>Range of individual dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhalation (radon gas)</td>
<td>1.26</td>
<td>0.2 – 10</td>
</tr>
<tr>
<td>External terrestrial</td>
<td>0.48</td>
<td>0.3 – 1</td>
</tr>
<tr>
<td>Ingestion</td>
<td>0.29</td>
<td>0.2 – 1</td>
</tr>
<tr>
<td>Cosmic radiation</td>
<td>0.39</td>
<td>0.3 – 1</td>
</tr>
<tr>
<td>Total natural</td>
<td>2.4</td>
<td>1 – 13</td>
</tr>
</tbody>
</table>


# Radiation In Low Earth Orbit - Limits

<table>
<thead>
<tr>
<th>Age</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>700</td>
<td>400</td>
</tr>
<tr>
<td>35</td>
<td>1000</td>
<td>600</td>
</tr>
<tr>
<td>45</td>
<td>1500</td>
<td>900</td>
</tr>
<tr>
<td>55</td>
<td>3000</td>
<td>1700</td>
</tr>
</tbody>
</table>

NCRP Report No. 132, Radiation Protection Guidance for Activities in Low-Earth Orbit
Radiation: Passive radiation detectors (TLDs)

**Thermoluminescence detectors (TLD)**

**Working principle:**

- Ionising radiation deposits energy within the TLD crystal matrix.
- Upon heating up the crystal the energy is released in the form of light.
- This light is proportional to the absorbed dose deposited in the crystal.

First usage of LiF (Lithiumfluoride) for the measurement of radiation following an atomic weapon test. Measurement of internal radiation dose received by cancer patients treated with radioactive isotopes at Oak Ridge Institute for Nuclear Studies.

**F. Daniels** *Science* **117**, 343, **1953**
**Radiation:** Passive radiation detectors (Track Etch Detectors)

**Nuclear Track Etch Detectors (CR-39)**

Material: CR-39 = allyl diglycol carbonate

**Working principle:**
- Heavy charged particles break chemical bonds in the material.
- This trail can be made visible by etching the material.


Picture size: 320 x 250 µm (as seen through a microscope)
DOSIS 3D: Active radiation detectors

Count rates (particles/s)

DoY (2012)

Data provided by: CAU, Kiel, and DLR, Cologne, Germany
**DOSIS 3D: Active radiation detectors**

![Graph showing count rates (particles/s) over DoY (2012)]

- Count rates (particles/s)
  - 1,000
  - 100
  - 10
  - 1

- Data provided by: CAU, Kiel, and DLR, Cologne, Germany

- South Atlantic Anomaly
- Galactic Cosmic Rays

**Data provided by**: CAU, Kiel, and DLR, Cologne, Germany
DOSIS 3D: Active radiation detectors

Data provided by: CAU, Kiel, and DLR, Cologne, Germany
DOSIS 3D: Active radiation detectors

Data provided by: CAU, Kiel, and DLR, Cologne, Germany
DOSIS 3D: Active radiation detectors

Data provided by: CAU, Kiel, and DLR, Cologne, Germany