Overview of TLD and OSL measurements at SCK•CEN in the framework of the DOSIS and DOSIS 3D and the most recent biological experiments

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Outline

- Introduction
- Methodology
- Experiments
  - DOSIS and DOSIS 3D
  - Biological experiments
- Conclusions and outlook
Introduction
Radiation doses in space are much higher than on earth
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  ⇒ A combination of different detectors is required to cover the whole LET spectrum
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- Radiation doses in space are much higher than on earth

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- Radiation fields in space are more complex than on earth

  ➔ A combination of different detectors is required to cover the whole LET spectrum

- Passive and compact dosimetry can be provided by the combination of TLDs, OSLDs and track-etch detectors
Methodology
Thermoluminescence detectors
Thermoluminescence detectors

- Detector types
  - TLD Poland
  - LiF:Mg,Ti: MTS-N, MTS-6 and MTS-7
  - LiF:Mg,Cu,P: MCP-N, MCP-6 and MCP-7
Thermoluminescence detectors

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- **Annealing**
  - LiF:Mg,Ti: 1h at 400°C, 2h at 100°C, slow cooling
  - LiF:Mg,Cu,P: 10min 240°C, fast cooling
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- **Reading**
  - Harshaw 5500
  - 1°C/s heating rate
  - No preheat
Thermoluminescence detectors
Thermoluminescence detectors

LiF:Mg,Ti

Integration interval 100°C – 260°C
Thermoluminescence detectors

LiF:Mg,Cu,P

Integration interval
170°C – 230°C

TL intensity [au]

Temperature [°C]
Optically stimulated luminescence detectors
Optically stimulated luminescence detectors

- Detector type
  - Landauer
  - $\text{Al}_2\text{O}_3$:C: Luxel
Optically stimulated luminescence detectors

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- Bleaching
  - One day exposure to ambient light
Optically stimulated luminescence detectors

- **Detector type**
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- **Bleaching**
  - One day exposure to ambient light

- **Reading**
  - 488 nm Ar⁺ laser
  - 120 mW/cm²
  - 100 s CW-OSL
Optically stimulated luminescence detectors

- mirror
- filter
- objective
- Ar+ laser
- Luxel filter
- PMT
Optically stimulated luminescence detectors

Luxel

Integration interval 0 s – 100 s

OSL intensity [au] vs. Stimulation time [s]
Calibration and background
Calibration and background

- Calibration
  - Separate detector group from same batch
  - 40 mGy $^{60}$Co in the middle of the flight
  - Individual sensitivity factor determined in advance for the TLDs
  - Doses expressed in terms of absorbed dose in water
Calibration and background

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  - Separate detector group from same batch
  - 40 mGy $^{60}$Co in the middle of the flight
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  - Doses expressed in terms of absorbed dose in water

- **Background**
  - Two separate detector groups from same batch
  - First group travels to launch site and back as background for boxes
  - Second group stays at SCK•CEN as background for the calibration
I. DOSIS and DOSIS 3D
DOSIS and DOSIS 3D

- Multilateral project lead by DLR
DOSIS and DOSIS 3D

- Multilateral project lead by DLR
- Monitoring the radiation environment in the Columbus module of the International Space Station
DOSIS and DOSIS 3D

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- Study of the spatial and temporal variations in the radiation field
DOSIS and DOSIS 3D

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- Monitoring the radiation environment in the Columbus module of the International Space Station
- Study of the spatial and temporal variations in the radiation field
- Variety of passive and active detectors
Passive detector packages

Passive detector packages

Absolute absorbed dose values
Absolute absorbed dose values

- Absorbed dose in water measured with TLDs and OSLDs
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Absolute absorbed dose values

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  - Average: 250 µGy/day
  - Standard deviation: 17%
  - Minimum: 153 µGy/day
  - Maximum: 389 µGy/day
Dose dependence on solar activity and altitude
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Daily dose values for each box and detector type normalized to their average over all experiments
Dose dependence on solar activity and altitude

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Dose dependence on solar activity and altitude

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[1] DOSIS 3D Science Team Coordinator Thomas Berger
Dose dependence on solar activity and altitude
Dose dependence on solar activity and altitude

- ± 30% variation over all experiments
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- Increasing solar activity => decreasing GCRs
Dose dependence on solar activity and altitude

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- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values
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- Increasing ISS altitude => increasing SAA dose
Dose dependence on solar activity and altitude

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- Increasing ISS altitude  => increasing SAA dose
  => higher absorbed dose values
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- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values

- Increasing ISS altitude => increasing SAA dose
  => higher absorbed dose values

- Similar trends for different detector types and different boxes
Dose dependence on solar activity and altitude

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- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values

- Increasing ISS altitude => increasing SAA dose
  => higher absorbed dose values

- Similar trends for different detector types and different boxes

- Larger scatter for Luxels
Dose dependence on shielding
Dose dependence on shielding

Daily dose values for each experiment and detector type normalized to their average over all boxes
Dose dependence on shielding

Daily dose values for each experiment and detector type normalized to their average over all boxes.
Dose dependence on shielding

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- ± 30% variation over all locations
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Dose dependence on detector type
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Daily dose values for each experiment and box normalized to their average over all detector types
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Daily dose values for each experiment and box normalized to their average over all detector types

- **DOSIS I**
- **DOSIS 3D I**
- **DOSIS II**
- **DOSIS 3D II**
Dose dependence on detector type

Daily dose values for each experiment and box normalized to their average over all detector types.
Dose dependence on detector type

Overview LET dependencies ICCHIBAN

Relative efficiency vs LET [keV/μm]

- MTS7
- MCP7
- Luxel
Dose dependence on detector type
Dose dependence on detector type

- ± 35% variation over all detector types
Dose dependence on detector type

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- Similar trends for different boxes and different experiments
  - MTS6 > MTS7 > Luxel > MCP6 > MCP7
  - Type 6 > type 7 due to neutron sensitivity
  - MTS > Luxel > MCP due to LET dependence
Dose dependence on detector type

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II. Biological experiments
Motivation

- Micro-organisms and plants are important for future long flights
  - Recycling of waste and production of food and oxygen
  - Negative effect on the crew health by causing infections
  - Bacteria with biodegradative and biocorrosive properties may jeopardize the integrity of the spatial hardware
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- Response of micro-organisms and plants to space conditions
  - Microgravity
  - Vibrations during launch
  - Changed electromagnetic field
  - Ionizing radiation
July 18 – September 1 2014
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FOTON-M4 satellite
- 250 – 550 km altitude (415 km for ISS)
- 64.9° inclination (51.6° for ISS)
FOTON-M4

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- Detectors
  - MTS-6, MTS-7, MCP-6, MCP-7
FOTON-M4

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- Experimental goals
  - NITRIMEL: Microgravity effect on nitrifying MELiSSA bacteria
  - pre-BIOROCK: Microgravity effect on Cupriavidus metallidurans CH34
FOTON-M4

Absorbed dose [µGy/day]

Position

pre-BIOROCK

MCP6
MCP7
MTS6
MTS7
## FOTON-M4

<table>
<thead>
<tr>
<th></th>
<th>FOTON-M4</th>
<th>DOSIS 3D V</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>566 µGy/day</td>
<td>245 µGy/day</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>27%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>329 µGy/day</td>
<td>196 µGy/day</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>1047 µGy/day</td>
<td>313 µGy/day</td>
</tr>
<tr>
<td><strong>MTS7/MTS6</strong></td>
<td>1.06</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>MCP7/MCP6</strong></td>
<td>0.99</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>MTS7/MCP7</strong></td>
<td>1.38</td>
<td>1.20</td>
</tr>
</tbody>
</table>
Significantly higher absorbed doses compared to ISS
- Lower shielding
- Higher altitude
- Higher inclination
• Significantly higher absorbed doses compared to ISS
  • Lower shielding
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• MTS7 > MTS6
  • Low statistics
  • Systematic shielding of detectors by each other
Significantly higher absorbed doses compared to ISS
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MTS7 > MTS6
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- Systematic shielding of detectors by each other

MTS/MCP is higher than for DOSIS 3D
- Lower shielding
September 2 – September 12 2015
September 2 – September 12 2015

Soyuz 44 => ISS => Soyuz 42
September 2 – September 12 2015

Soyuz 44 => ISS => Soyuz 42

Detectors

- SCK•CEN: MTS-6, MTS-7, MCP-6, MCP-7
- NPI: CR-39
September 2 – September 12 2015

Soyuz 44 => ISS => Soyuz 42

Detectors
- SCK•CEN: MTS-6, MTS-7, MCP-6, MCP-7
- NPI: CR-39

Experimental goals
- Exposure of key MELiSSA micro-organisms
- Can they withstand space travel in a metabolically inactive state?
- Are they fully functional upon reactivation after the flight?
End 2016
● End 2016

● SpaceX capsule => ISS => Soyuz
End 2016

SpaceX capsule => ISS => Soyuz

Detectors
- SCK•CEN: MTS-6, MTS-7, MCP-6, MCP-7, Luxel
- NPI: CaSO$_4$:Dy, Al$_2$O$_3$:C, CR-39
End 2016

SpaceX capsule => ISS => Soyuz

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Experimental goals
- Effect of spaceflight conditions on MELiSSA bacteria for CO$_2$ and nitrate removal and oxygen and biomass production
Conclusions and outlook
SCK•CEN has been involved in many space experiments using TLDs and OSLDs
- DOSIS and DOSIS 3D
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- The dose values and their trends with orbital parameters, solar activity, shielding and detector type are consistent
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- A PhD student is starting in October 2015 to investigate the LET dependence of glow curves and OSL decay curves
Optically stimulated luminescence detectors

488 nm laser peak

450 nm long pass filter behind laser objective

Optically stimulated luminescence detectors

390-430 nm interference filter in front of PMT

450 nm long pass filter behind laser objective

III. Weather balloon experiment
Weather balloon experiment
Weather balloon experiment

- June 29 2015
Weather balloon experiment

- June 29 2015

- Helium balloon with instrumentation box attached
  - ± 90 min ascending up to ± 30 km height
  - ± 30 min descending with parachute
Weather balloon experiment

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- Detectors
  - MCP-N
  - EPD-N2
    - Si PIN diode with H rich polymer shield => fast neutrons
    - Si PIN diode with $^{6}$Li shield => slow neutrons
    - bare Si PIN diode => gamma’s (+ electrons, protons, muons ?)
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- Experimental goal
  - Comparison of radiation field on the ground and in the stratosphere
Weather balloon experiment
Flight path
Contribution of the different particles to radiation field

Neutron energy spectrum

Predicted effective dose based on CARI-6M

[1] https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6m/
Predicted effective dose based on CARI-6M

- Program developed by the Federal Aviation Administration’s Civil Aerospace Medical Institute

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- Calculates the effective dose due to galactic cosmic radiation for a given trajectory

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- Total effective dose of 12.8 µSv in two hours

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EPD-N2 results

- 1.5 h with significantly elevated dose rate
- Shown values take into account the EPD-N2’s overresponse for the high energy neutron field with factor of ±8 [1]

Results overview

- **EPD-N2**
  - 10.5 μSv neutron dose
  - 5 μSv gamma dose (+ electrons, protons, muons ?)
  - 15.5 μSv total dose
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- **CARI-6M prediction**
  - 12.8 µSv total effective dose