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Pille Measurements on ISS (September 2022 – March 2024)
and the latest upgrade of the Pille System

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Outline

- Introduction
- September 2022 – March 2024 data
- Comprehensive analysis of the Pille EVA doses
- Upgrade of the Pille-MKS system with new type of Pille dosimeters

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Introduction

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The Pille TLD system

- Space qualified TL system with on-board reader
- Bulb dosimeter (CaSO4:Dy) in dosimeter key
  - Ø 20 mm * 60 mm
  - 70 g (with protective case)
  - Built-in chip with unique ID and calibration data
- Measuring range (s<10%): 3 µGy … 10 Gy ($CaSO_4$:Dy)
- TLD Efficiency for $LET_\infty(H_2O)$ < 10 keV/µm: ε=1±10%
- Accuracy (above 10 µGy): δ < 5%

Credits: IMBP/Roscosmos/Enyergia

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Accuracy and corrections

- Usual accuracy: ±10%
- Bulbs are selected for flight for which the reproducibility is within an accuracy of 5%.
- Dosimeters are calibrated with a standard ^{137}Cs source beam (gamma-rays) on ground (air kerma).
- Data presented by HUN-REN EK are not corrected for LET_{H_2O}>10 keV/µm.
- No conversion to absorbed dose in water or tissue-equivalent material is applied by HUN-REN EK. Russian specialists use a conversion factor of 1.1.

Credits: IMBP/Roscosmos/Enyergia

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The Pille TLD system

- Since 1980, on board Salyut-6,-7, Space Shuttle, Mir, ISS
- DOSMAP project in 2001
- Service dosimetry system on Zvezda since 2003 (Exp. #8)
  - Dose mapping
  - Personal dosimetry during SPE-s
  - Personal dosimetry during EVA-s
  - Automatic read-out on every orbit (90-min)
- Original kit (in 2003): a Pille reader and a set of 10 dosimeters

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The Pille TLD system

- Original kit (in 2003): a Pille reader (No. 16) and a set of 10 dosimeters (A0301 – A0310)
- 4 new dosimeters (A0311 – A0314) were delivered to ISS and 2 old ones (A0303, A0308) retrieved in 2009 (Simonyi's 2nd flight)
- Warranty period got over
- A new reader (No. 20) and 5 additional dosimeters (A0151 – A0155) delivered to ISS in June 2018; A0301 and A0306 out of use since Aug 2018

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September 2022 – March 2024 data

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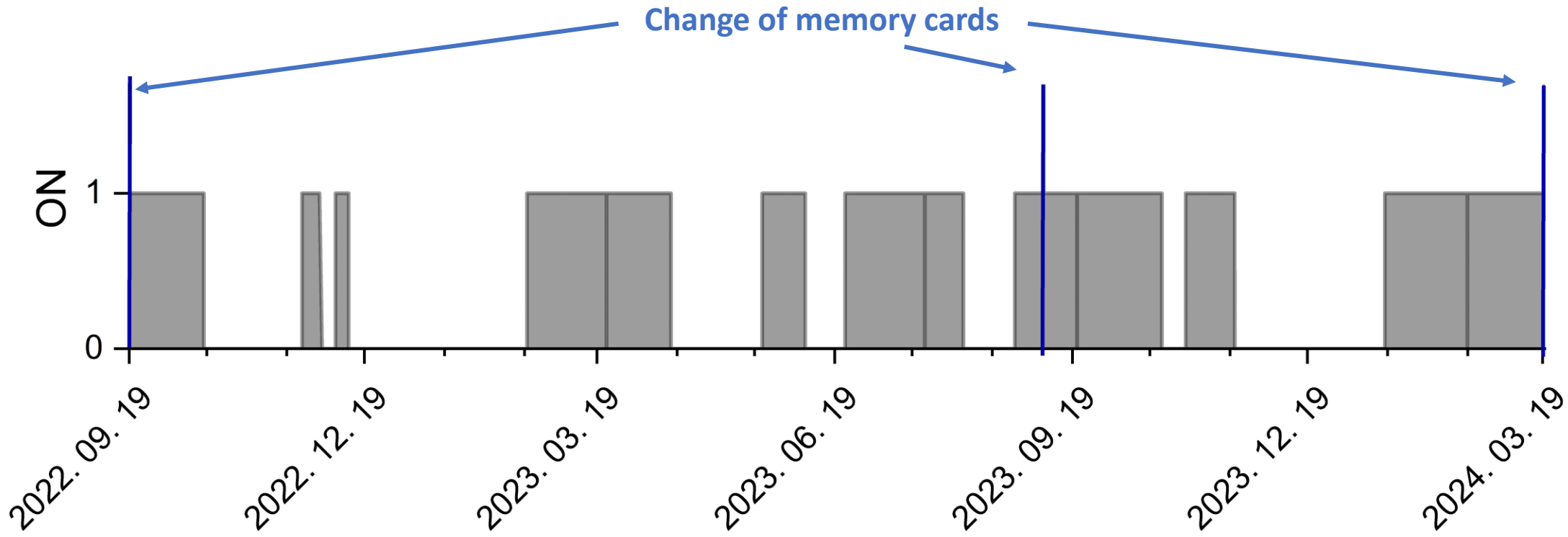
Automatic measurements with dosimeter #A0151

Availability: only 54%

After manual read-outs, unfortunately,. automatic measurements are not always restarted



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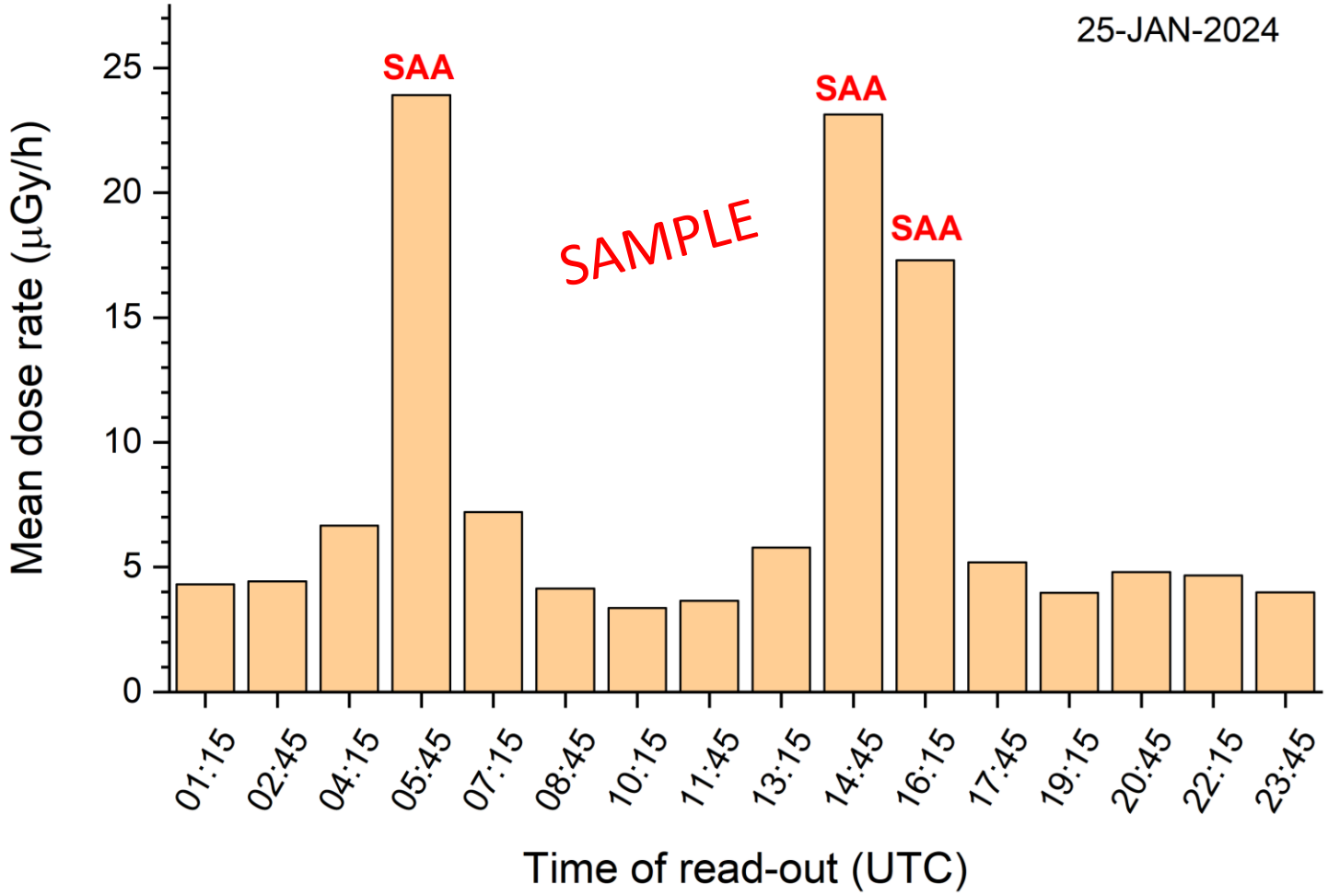
Automatic measurements with dosimeter #A0151



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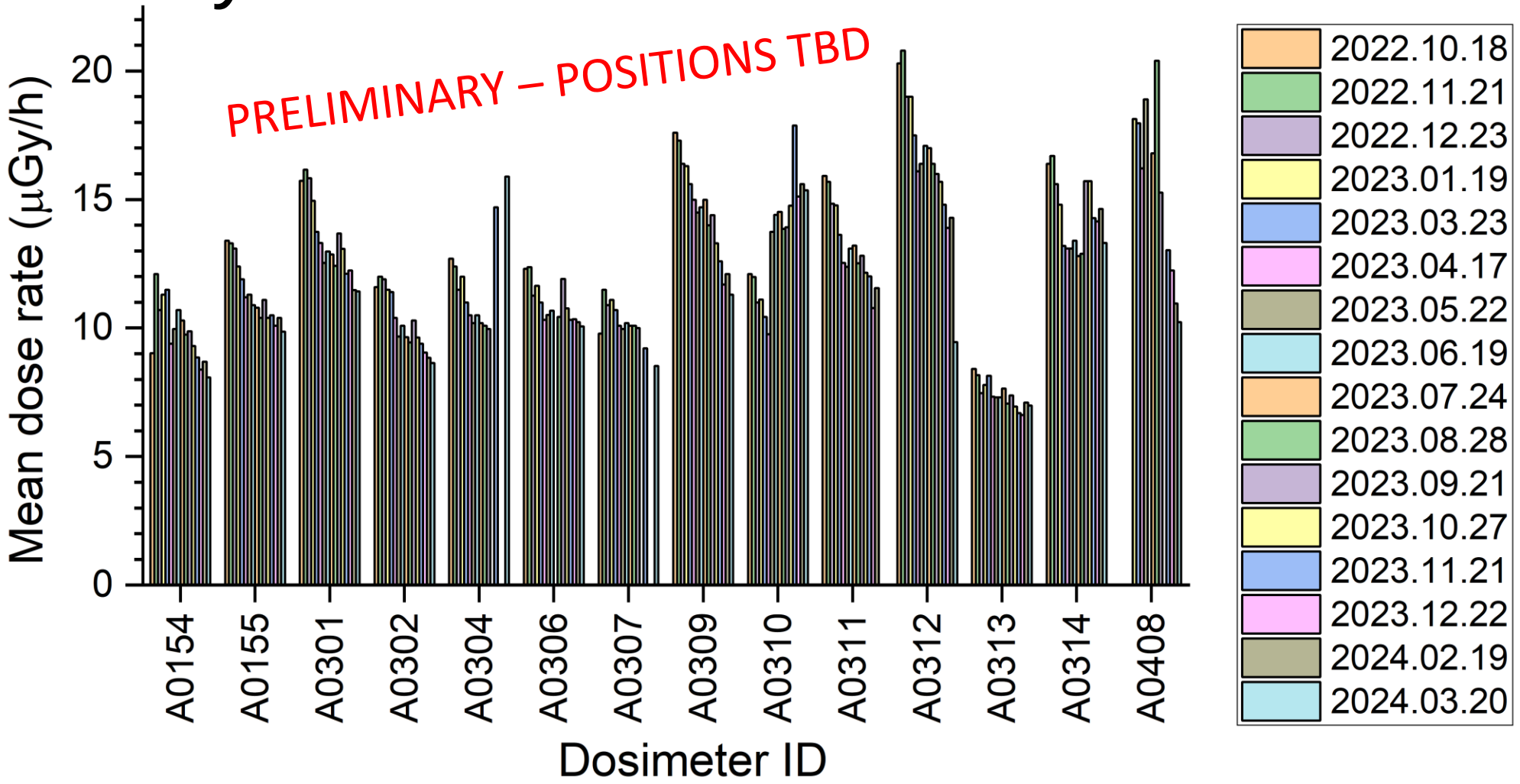
Monthly read-outs



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EVA doses

$$D_{EVA,extra} = D_{EVA,readout} - D_{ref,readout} \quad (1)$$

$$D_{EVA,ref} = d_{ref,readout} * t_{EVA} \quad (2)$$

$$d_{EVA,mean} = \frac{D_{EVA,extra} + D_{EVA,ref}}{t_{EVA}} \quad (3)$$

- Dosimeters used for EVA dosimeter: A0152, A0153, A0402, A0403
- For reference dosimeter: A0305, A0408

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EVA doses (example)

US EVA-81; Nov. 15, 2022. 14:14–21:25 UTC; duration 7 hrs 11 min

Reference dosimeter: A0305 (…)

Dosimeter	Total readout dose [μGy] (time [h])	$D_{EVA,extra}$ [μGy]	$d_{EVA,mean}$ [μGy/h]
A0305	510 (53.7)	-	-
A0152	649 (49.4)	139	28.8
A0153	864 (49.4)	354	58.7

RS EVA-56; Nov. 17, 2022. 14:39–21:07 UTC; duration 6 hrs 25 min

Reference dosimeter: A0305 (…)

Dosimeter	Total readout dose [μGy] (time [h])	$D_{EVA,extra}$ [μGy]	$d_{EVA,mean}$ [μGy/h]
A0305	462 (45.6)	-	-
A0152	1430 (45.6)	968	161
A0153	1680 (45.6)	1221	200

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Comprehensive analysis of Pille EVA doses

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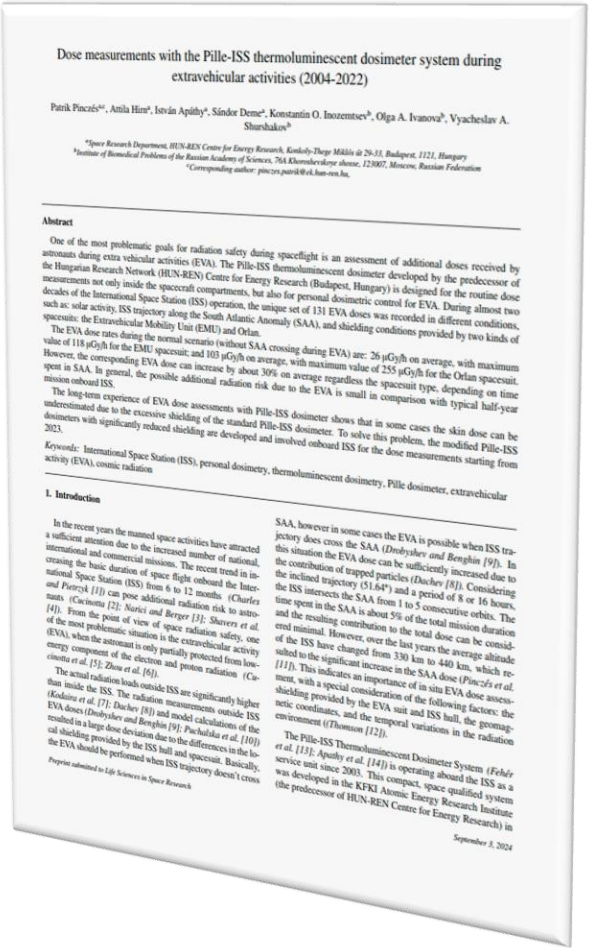
Dose measurements with the Pille-ISS thermoluminescent dosimeter system during extravehicular activities (2004-2022)

- Manuscript to be submitted to LSSR soon
- Results are only for information of the WRMISS community
- 131 EVA doses were recorded in different conditions (solar activity, ISS trajectory along the SAA, and shielding conditions provided by two kinds of spacesuits: the Extravehicular Mobility Unit (EMU) and Orlan).



Dose measurements with the Pille-ISS thermoluminescent dosimeter system during extravehicular activities (2004-2022)

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Abstract

One of the most problematic goals for radiation safety during spaceflight is an assessment of additional doses received by astronauts during extra vehicular activities (EVA). The Pille-ISS thermoluminescent dosimeter developed by the predecessor of the Hungarian Research Network (HUN-REN) Centre for Energy Research (Budapest, Hungary) is designed for the routine dose measurements not only inside the spacecraft compartments, but also for personal dosimetric control for EVA. During almost two decades of the International Space Station (ISS) operation, the unique set of 131 EVA doses was recorded in different conditions, such as: solar activity, ISS trajectory along the South Atlantic Anomaly (SAA), and shielding conditions provided by two kinds of spacesuits: the Extravehicular Mobility Unit (EMU) and Orlan.

The EVA dose rates during the normal scenario (without SAA crossing during EVA) are: 26 μGy/h on average, with maximum value of 118 μGy/h for the EMU spacesuit; and 103 μGy/h on average, with maximum value of 255 μGy/h for the Orlan spacesuit. However, the corresponding EVA dose can increase by about 30% on average regardless the spacesuit type, depending on time spent in SAA. In general, the possible additional radiation risk due to the EVA is small in comparison with typical half-year mission onboard ISS.

The long-term experience of EVA dose assessments with Pille-ISS dosimeter shows that in some cases the skin dose can be underestimated due to the excessive shielding of the standard Pille-ISS dosimeter. To solve this problem, the modified Pille-ISS dosimeters with significantly reduced shielding are developed and involved onboard ISS for the dose measurements starting from 2023.

Keywords: International Space Station (ISS), personal dosimetry, thermoluminescent dosimetry, Pille dosimeter, extravehicular activity (EVA), cosmic radiation

1. Introduction

In the recent years the manned space activities have attracted a sufficient attention due to the increased number of national, international and commercial missions. The recent trend in increasing the basic duration of space flight onboard the International Space Station (ISS) from 6 to 12 months (*Charles and Pietrzyk [1]*) can pose additional radiation risk to astronauts (*Cucinotta [2]; Nuriel and Berger [3]; Shavers et al. [4]*). From the point of view of space radiation safety, one of the most problematic situation is the extravehicular activity (EVA), when the astronaut is only partially protected from low-energy component of the electron and proton radiation (*Cucinotta et al. [5]; Zhou et al. [6]*).

The actual radiation loads outside ISS are significantly higher than inside the ISS. The radiation measurements outside ISS (*Kodaira et al. [7]; Dachev [8]*) and model calculations of the EVA doses (*Drobyshev and Benghin [9]; Puchalska et al. [10]*) resulted in a large dose deviation due to the differences in the local shielding provided by the ISS hull and spacesuit. Basically, the EVA should be performed when ISS trajectory doesn't cross SAA, however in some cases the EVA is possible when ISS trajectory does cross the SAA (*Drobyshev and Benghin [9]*). In this situation the EVA dose can be sufficiently increased due to the contribution of trapped particles (*Dachev [8]*). Considering the inclined trajectory (51.64°) and a period of 8 or 16 hours, the ISS intersects the SAA from 1 to 5 consecutive orbits. The time spent in the SAA is about 5% of the total mission duration and the resulting contribution to the total dose can be considered minimal. However, over the last years the average altitude of the ISS have changed from 330 km to 440 km, which resulted to the significant increase in the SAA dose (*Pinczés et al. [11]*). This indicates an importance of in situ EVA dose assessment, with a special consideration of the following factors: the shielding provided by the EVA suit and ISS hull, the geomagnetic coordinates, and the temporal variations in the radiation environment (*Thomson [12]*).

The Pille-ISS Thermoluminescent Dosimeter System (*Apáthy et al. [13]; Apathy et al. [14]*) is operating aboard the ISS as a service unit since 2003. This compact, space qualified system was developed in the KFKI Atomic Energy Research Institute (the predecessor of HUN-REN Centre for Energy Research) in

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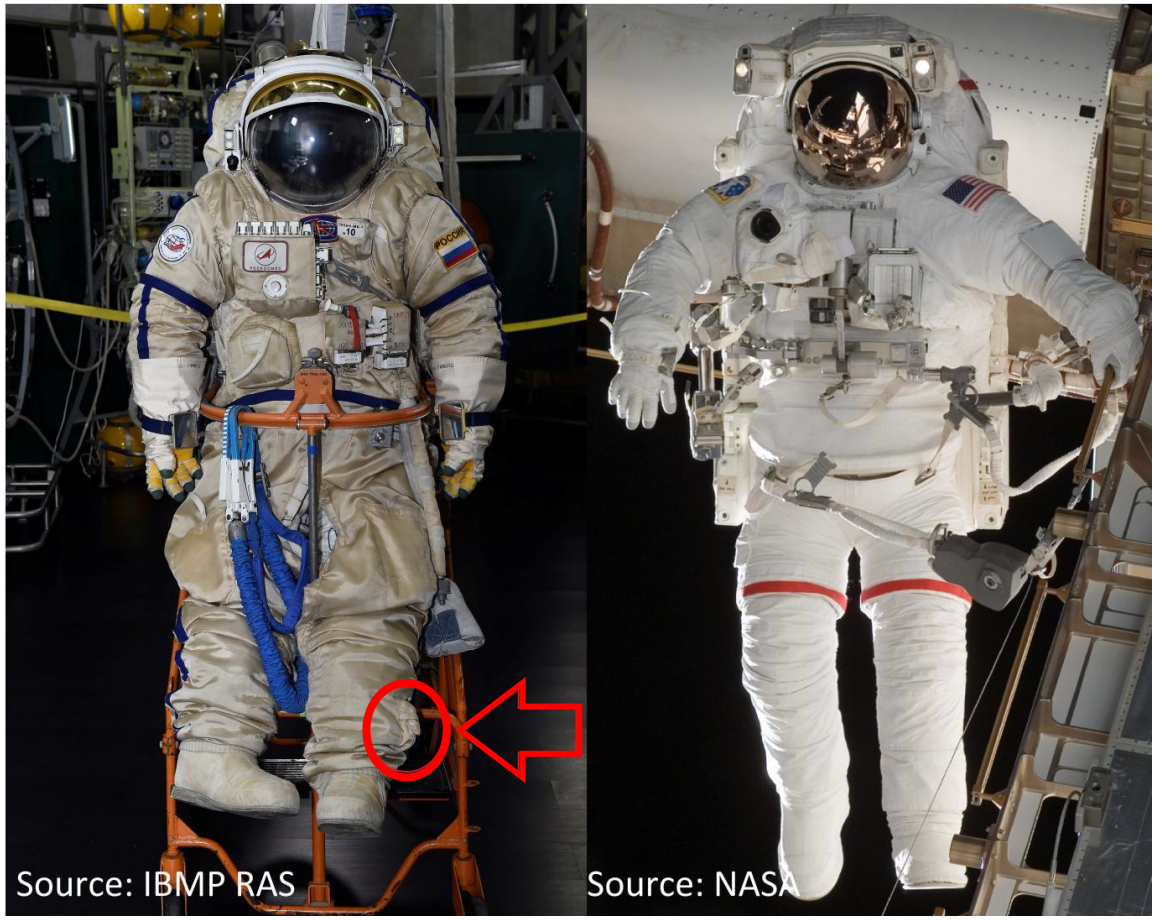
Pille mean EVA dose rates (2004-2022)

- Dosimeter in a pocket on the outside of the spacesuit:
  - Orlan: at the leg
  - EMU: at the shoulder? (TBC)



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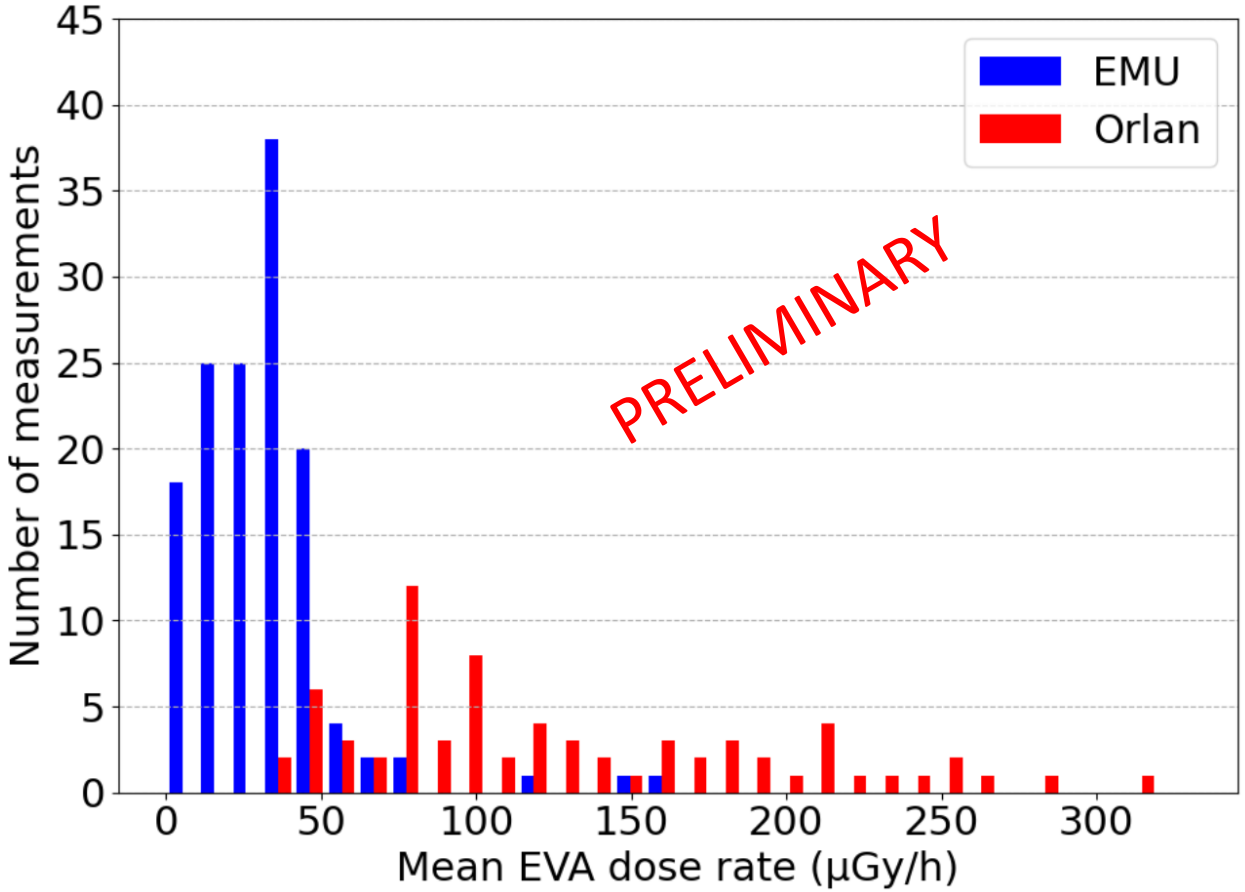
Pille mean EVA dose rates (2004-2022)

- Difference: most probably due to different shielding configuration



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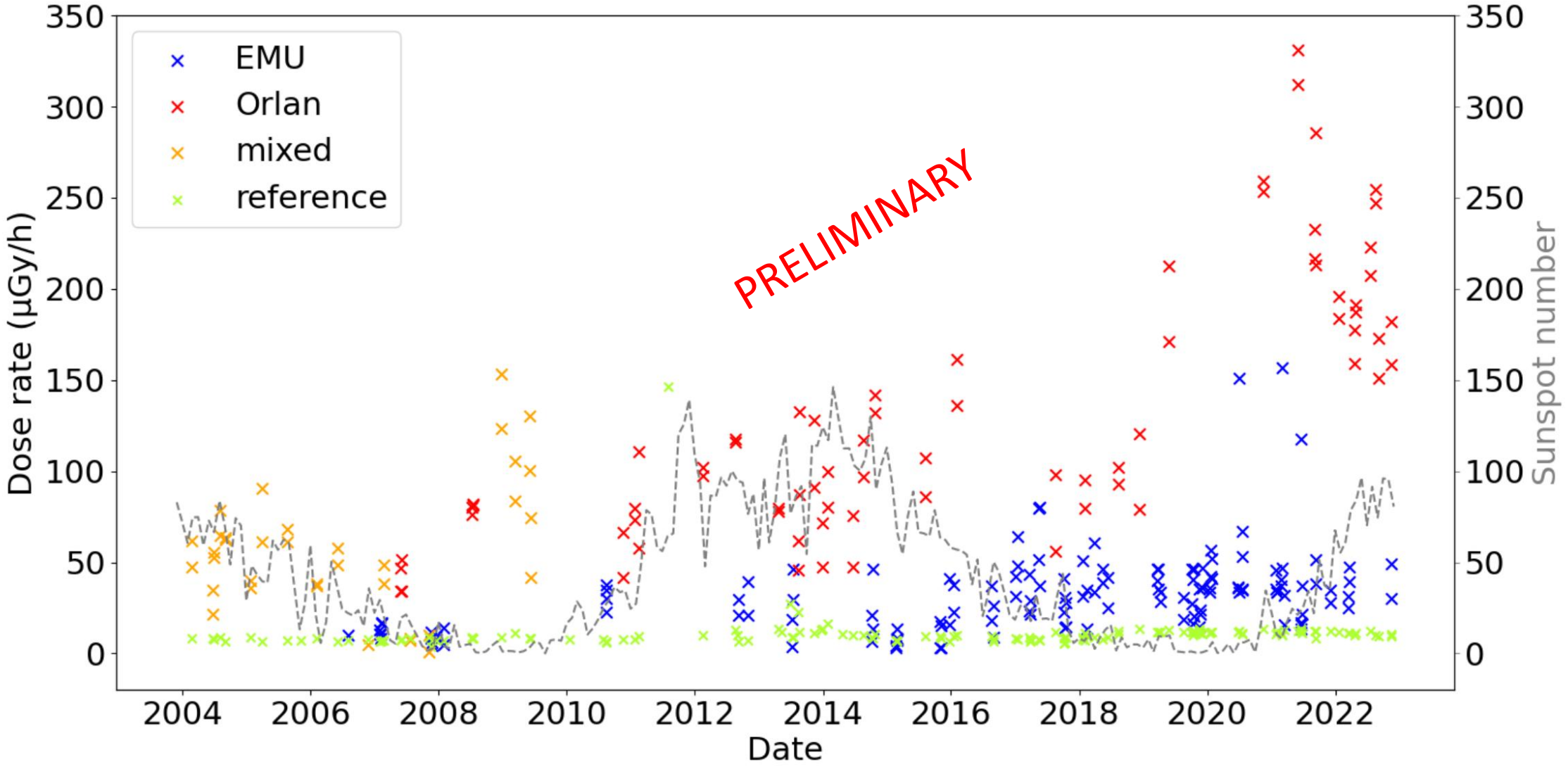

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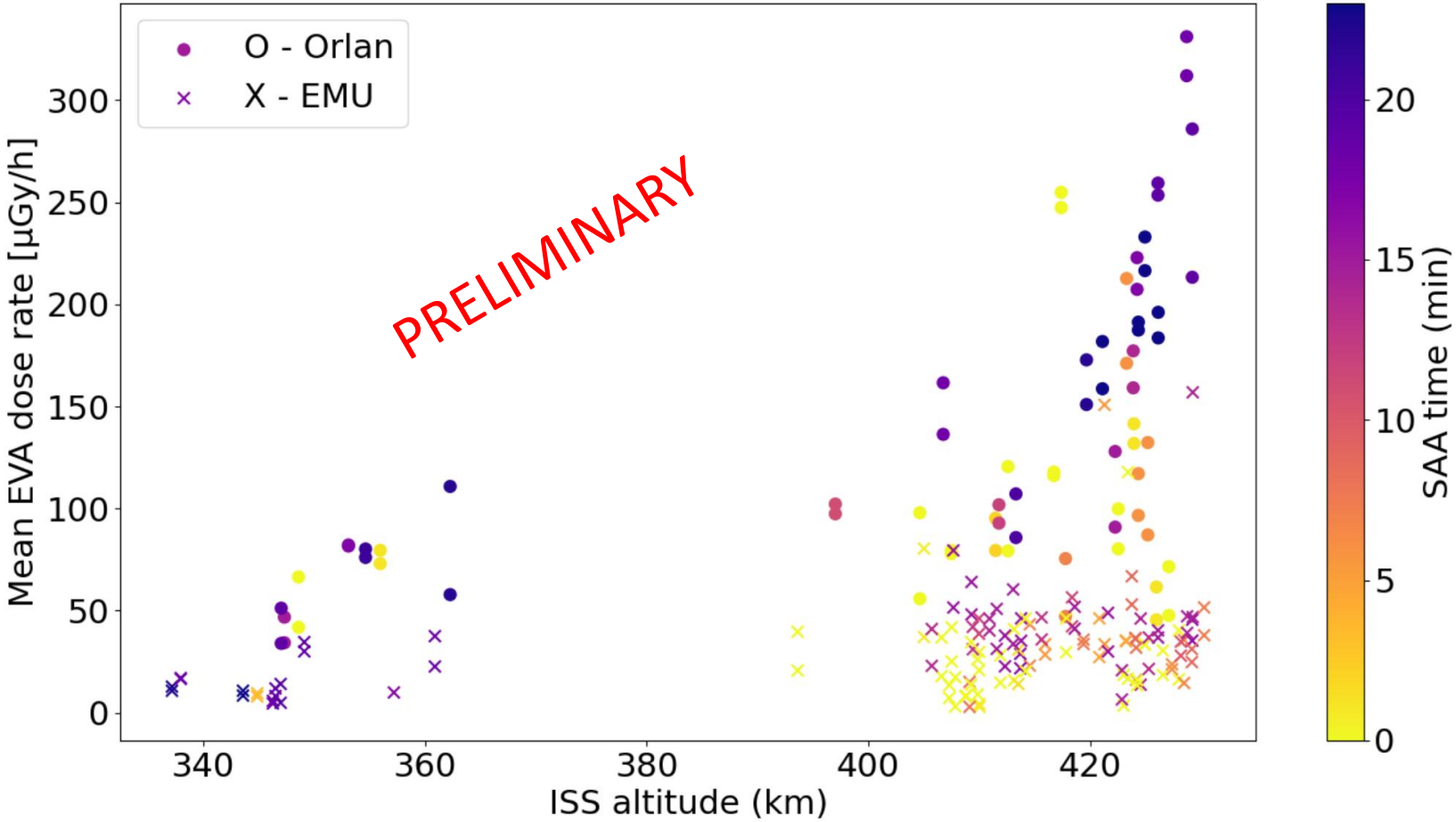
Pille mean EVA dose rates (2004-2022)



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Pille mean EVA dose rates (2004-2022)

- Based on Pille-ISS EVA measurements, the mean dose rates during EVA with SAA crosses are at least 30% higher on average for both suits.
- The maximum increase based on median values are 70% for EMU and 54% for Orlan.
- The large difference between the mean EVA dose rates measured on Orlan and EMU (different shielding conditions of the Pille ISS dosimeter): the shin (Orlan) are exposed to a higher solid angle compared to the tool bag (EMU).

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Upgrade of the Pille-MKS system with new type of Pille dosimeters

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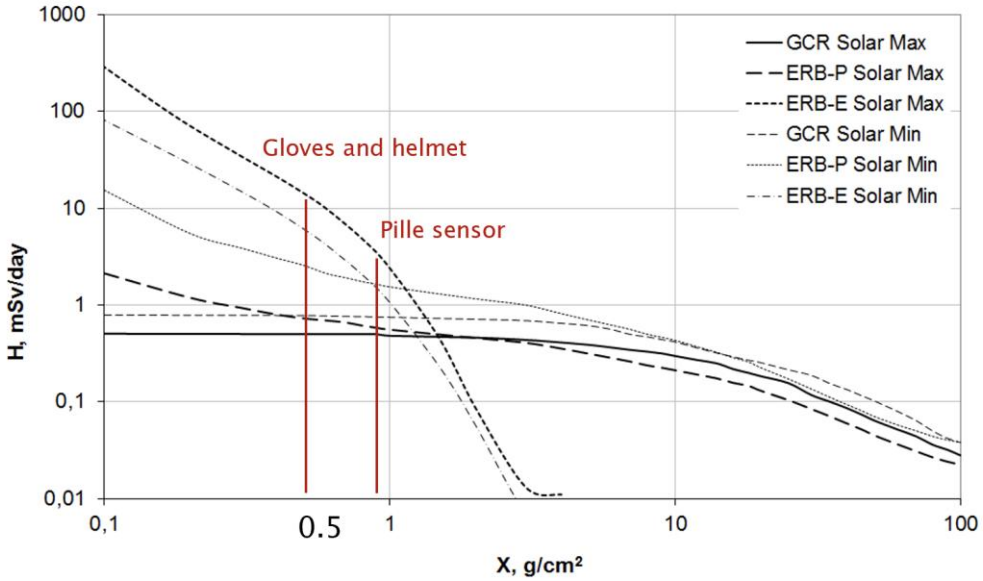
Motivation

- Pille electron sensitivity can be increased by removing the protective metal case (Hirn, 12th WRMISS, 2007)

Depth-dose curves for GCR and ERB protons and electrons at ISS orbit (400 km altitude, 51.6^0 inclination) in solar maximum and minimum*



*Kartashov,Shurshakov Acta Astronautica 144, 2018.

Skin and eye lens shielded ~0.4 and ~ 0.5 g/cm^2 thickness by spacesuit parts (gloves and helmet).
Pille sensor has ~0.9 g/cm^2 thickness.

Gorokhova et al 2018
23rd WRMISS, Tsuruga, Japan, September 2018

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New type of Pille dosimeters for EVA

	Envelope dimensions	Total mass, g	Shielding Al-equivalent in the lateral direction, $g \cdot cm^{-2}$	Minimal energy of low penetrating cosmic particles, MeV
Standard PILLE-ISS Dosimeter	120 mm x Ø23 mm	90	1.6	Electrons: 3.2 MeV Protons: 30 MeV
Modified PILLE-ISS Dosimeter	42 mm x Ø13 mm	10	0.5	Electrons: 1.2 MeV Protons: 16 MeV

#A0402, #A0403, #A0404, #A0406, #A0408

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New type of Pille dosimeters for EVA

- Pre-flight calibration with 150 MeV protons
- On-board cross-calibrations
- Variability of the relative TL sensitivities does not exceed (5–10)%
- The additional EVA dose did not exceed (0.37–0.75) mGy (in water).
  - consistent with the previous readings of other dosimetric equipment installed on the outer surface of ISS,
  - also consistent with the readings of other onboard instruments (such as onboard dosimeter R-16).

Radiation Measurements

Upgrade of the Hungarian PILLE-ISS onboard thermoluminescent system for the dose assessment during extravehicular activities

Hirn et al 2024
(Radiat Meas 177, 107255)

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In memoriam Sándor Deme

- The father of the Hungarian space dosimetry activities (esp. Pille, TRITEL)
- Contributions to radiation protection and safety of space station crew (and workers in nuclear facilities)
- Motivating teacher/supervisor, friend

Sándor Deme (1936 – 2024)

WRMISS in 2013 in Budapest

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Thank you for your attention!

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