Long term dose monitoring onboard the European Columbus module of the International Space Station (ISS) in the frame of the DOSIS and DOSIS 3D project

Thomas Berger for the DOSIS & DOSIS 3D Team

Radiation Biology Department
Institute of Aerospace Medicine
German Aerospace Center
51147 Cologne
Germany

DLR

DOSIS & DOSIS 3D: Science Team

Berger Thomas[1], Burmeister Sönke[2], Bilski Pawel[3], Horwacik Tomasz[3], Twardak Anna[3], Przybyla Bartos[1], Hajek Michael[4,5], Hofstätter Christina[5], Palfalvi Jozsef[6], Szabo Julianna[6], Ambrozova Iva[7], Vanhavere Filip[8], Gaza Ramona[9,15], Semones Edward[9], Yukihara Eduardo[10], Benton Eric[10], Labrenz Johannes[2], Uchihori Yukio[11], Kodaira Satoshi[11], Kitamura Hisashi[11], Shurshakov Vyacheslav[12], Tolochek Raisa[12], Nagamatsu Aiko[13], Boehme Matthias[14], Reitz Günther[1]

[1]DLR	German Aerospace Center	Cologne, Germany
[2]CAU	Christian Albrechts Universität zu Kiel	Kiel, Germany
[3]IFJ	Institute of Nuclear Physics	Krakow, Poland
[4]IAEA	International Atomic Energy Agency	Vienna, Austria
[5]ATI	Technical University Vienna	Vienna, Austria
[6]CER-HAS	Centre for Energy Research	Budapest, Hungary
[7]NPI	Nuclear Physics Institute	Prague, Czech Republic
[8]SCK-CEN	Belgian Nuclear Research Center	Mol, Belgium
[9]NASA	Space Radiation Analysis Group	Houston, United States
[10]OSU	Oklahoma State University	Stillwater, United States
[11]NIRS	National Institute of Radiological Sciences	Chiba, Japan
[12]IMBP	Russian Academy of Sciences	Moscow, Russia
[13]JAXA	Japan Aerospace Exploration Agency	Tsukuba, Japan
[14]OHB System AG		Bremen, Germany
[15]Lockheed Martin Exploration & Mission Support		Houston, United States

DOSIS & DOSIS 3D: Columbus

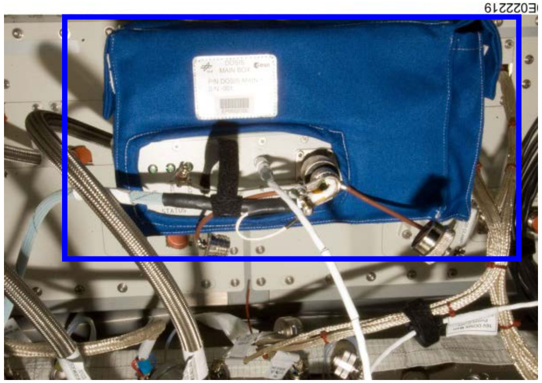
ISS023E044747

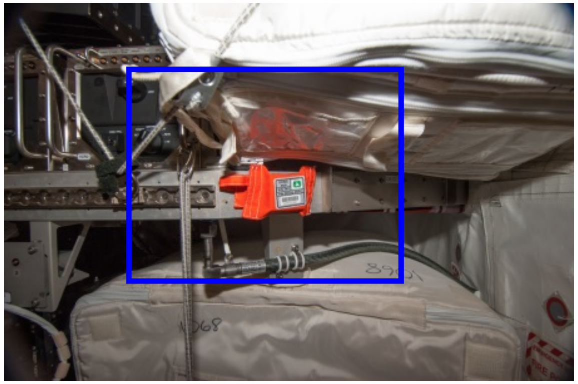
DOSIS & DOSIS 3D: Scientific Goals

The main objective of the **DOSIS & DOSIS 3D** experiment is the determination of the absorbed dose and dose equivalent using a variety of active and passive radiation detector devices distributed throughout the ISS.

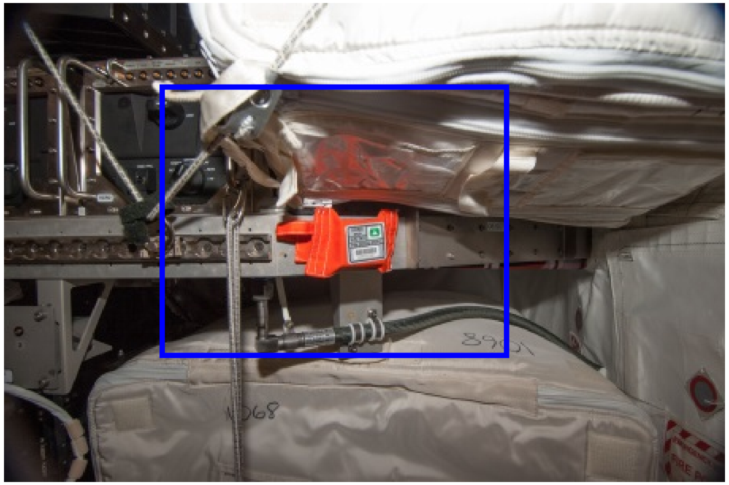
- Monitor the radiation environment inside Columbus with **active** and **passive** radiation detectors (ESA) for the determination of the temporal and spatial dose distribution

- Combine data gathered by NASA, JAXA, IMBP and ESA into a 3D radiation map of the International Space Station





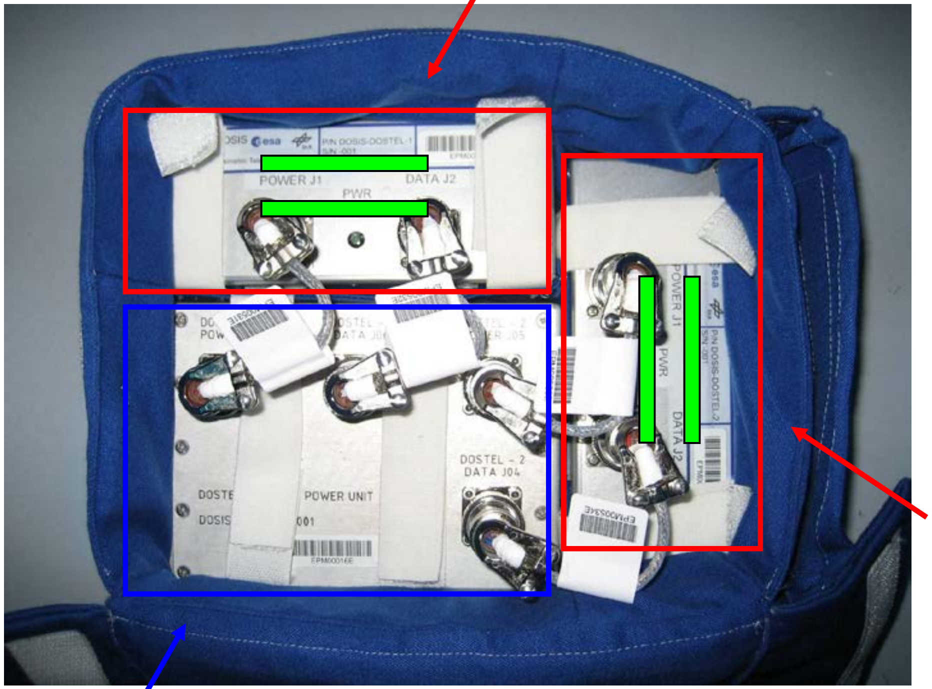
DOSIS & DOSIS 3D: Radiation Detectors



DOSIS & DOSIS 3D: Active

Dosis Main Box
DOSIS-MAIN-1-001

DOSTEL 1

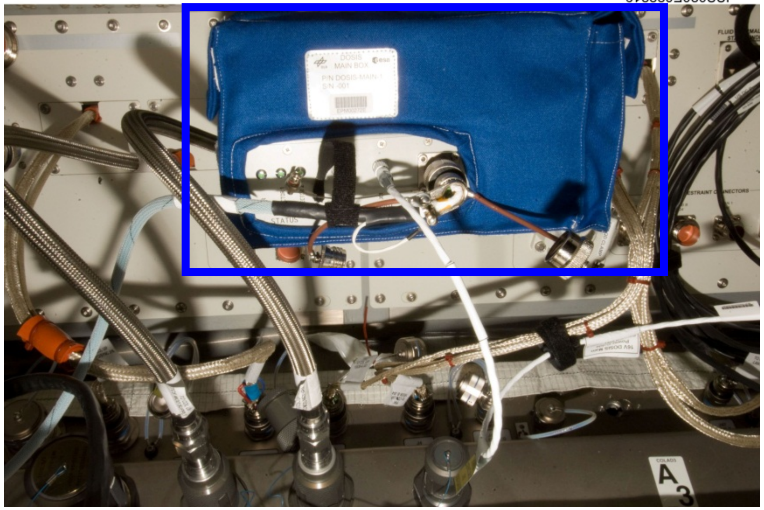


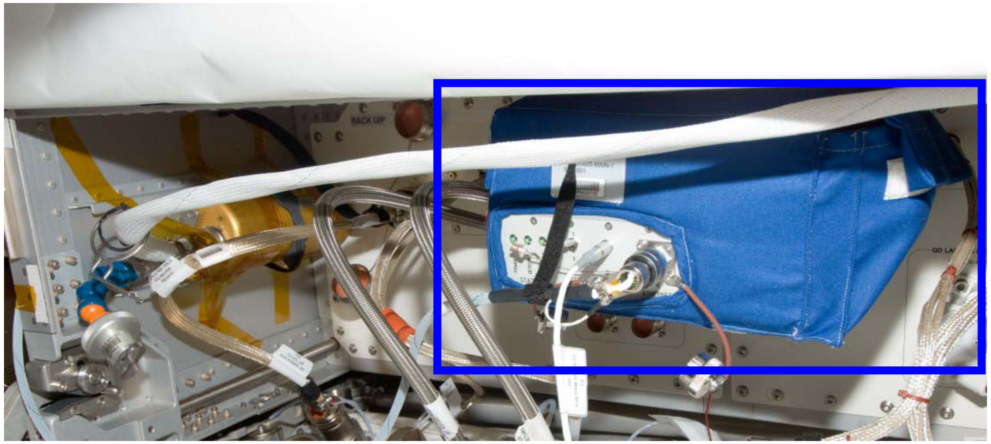
DOSTEL 2

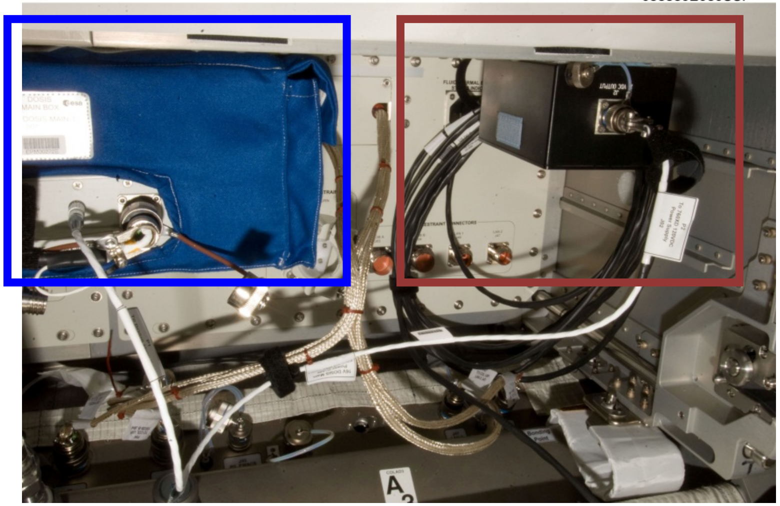
DDPU – DOSTEL Data/Power Unit

DOSTEL = Dosimetry Telescope

DOSIS & DOSIS 3D: Active



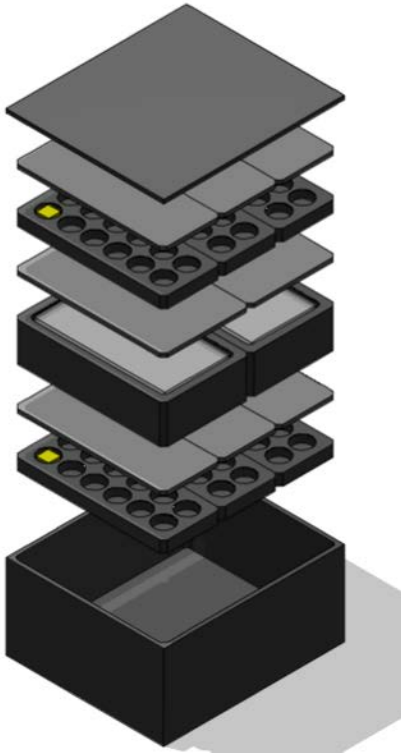


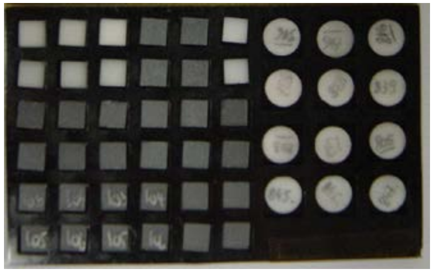


- Ethernet connection to EPM rack "Right Utility Distribution Panel“
- DOSIS MAIN BOX connected to EPM LAN like an external EPM instrument
- Data downlink is an EPM operation from ground performed once per month

CADMOS → COL-CC → MUSC → Scientists

DOSIS & DOSIS 3D: Passive Detector Packages (PDP)



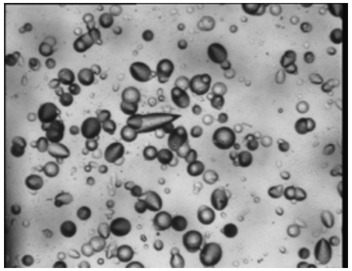


Thermoluminescence detectors (TLD)

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 radioactiv isotopes at Oak Ridge Institute for Nuclear Studies

F. Daniels *Science* **117**, 343**, 1953**



Nuclear Track Etch Detectors (CR-39)

Material : CR-39 = allyl diglycol carbonate

Heavy charged particles break chemical bonds in the material.This trail can be made visible by etching the material.

R. P. Henke and E. V. Benton, Nucl.Instr.Meth. 97 (**1971**) 483-9

TLD + CR-39 → Absorbed dose + Dose Equivalent

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DOSIS & DOSIS 3D: PDP Positions

PDP Nr	Columbus Location	Related Rack	Position		Columbus coordinate system [cm]		
					X	Y	Z
1	Star Cone	-	Behind bend in right cone structure	Aft	681	-57	0
2	A4 UIP	HRF 2	Left side on UIP next to Vacuum connector	Aft	665	-123	-93
3	F4 UIP	HRF 1	Left side on UIP next to Vacuum connector	Forward	570	123	-93
4	B1 HRF 1	HRF 1	Front panel of Cooling Stowage Drawer	Forward	600	104	60
5	A3 EPM	EPM	410mm left from upper right edge	Aft	463	-104	93
6	A2 UIP	BLB	Left side on UIP next to Vacuum connector	Aft	436	-123	-93
7	O2 UIP	-	Left side on UIP next to Vacuum connector	Aft	436	-101	106
8	F1 UIP	EDR	Left side on UIP next to Vacuum connector	Forward	243	123	-93
9	F1 EDR	EDR	77mm left from upper right edge	Forward	333	104	93
10	End Cone	-	On PBA Cover	Forward	221	95	85
X	DOSIS-MAIN-BOX	EPM	On the left side of the DOSIS-MAIN-BOX	Aft	516	-116	-60

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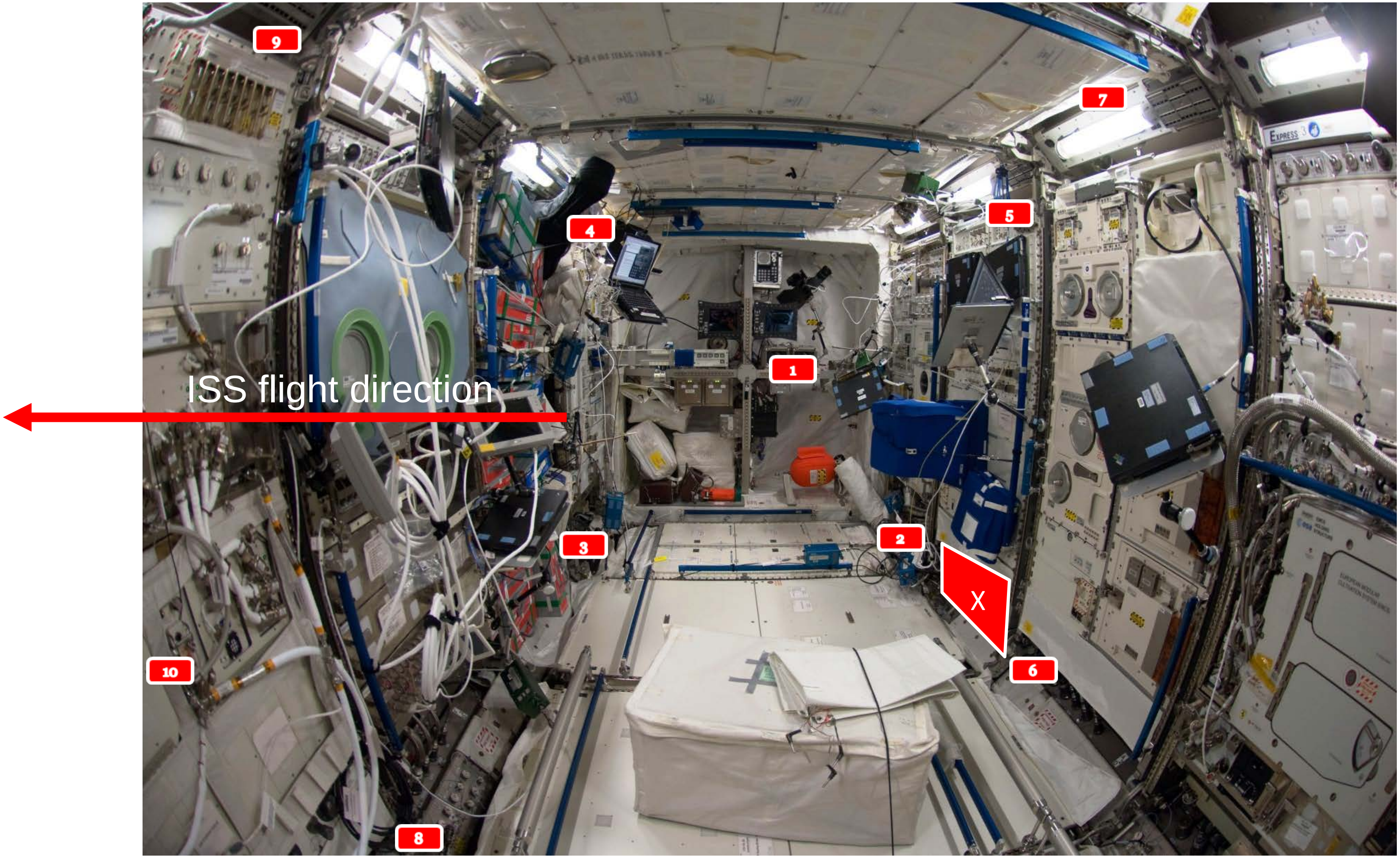
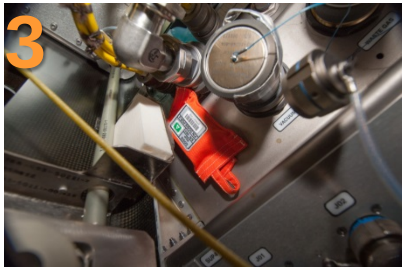
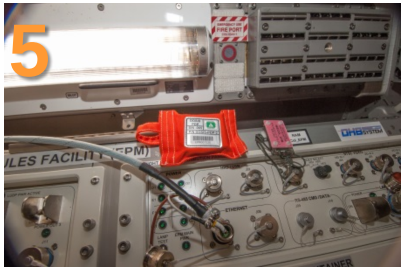
DOSIS & DOSIS 3D: PDP Positions



DOSIS & DOSIS 3D: PDP Positions





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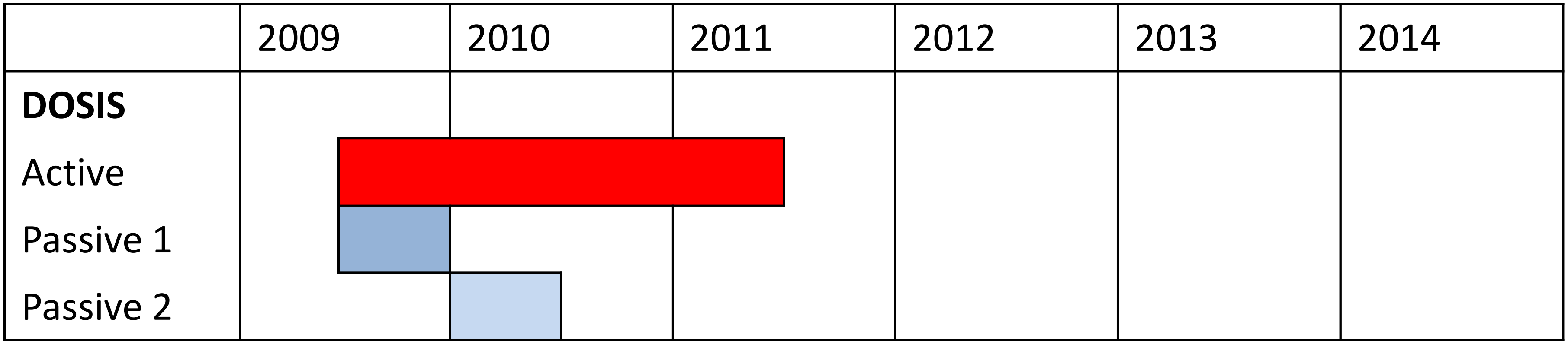
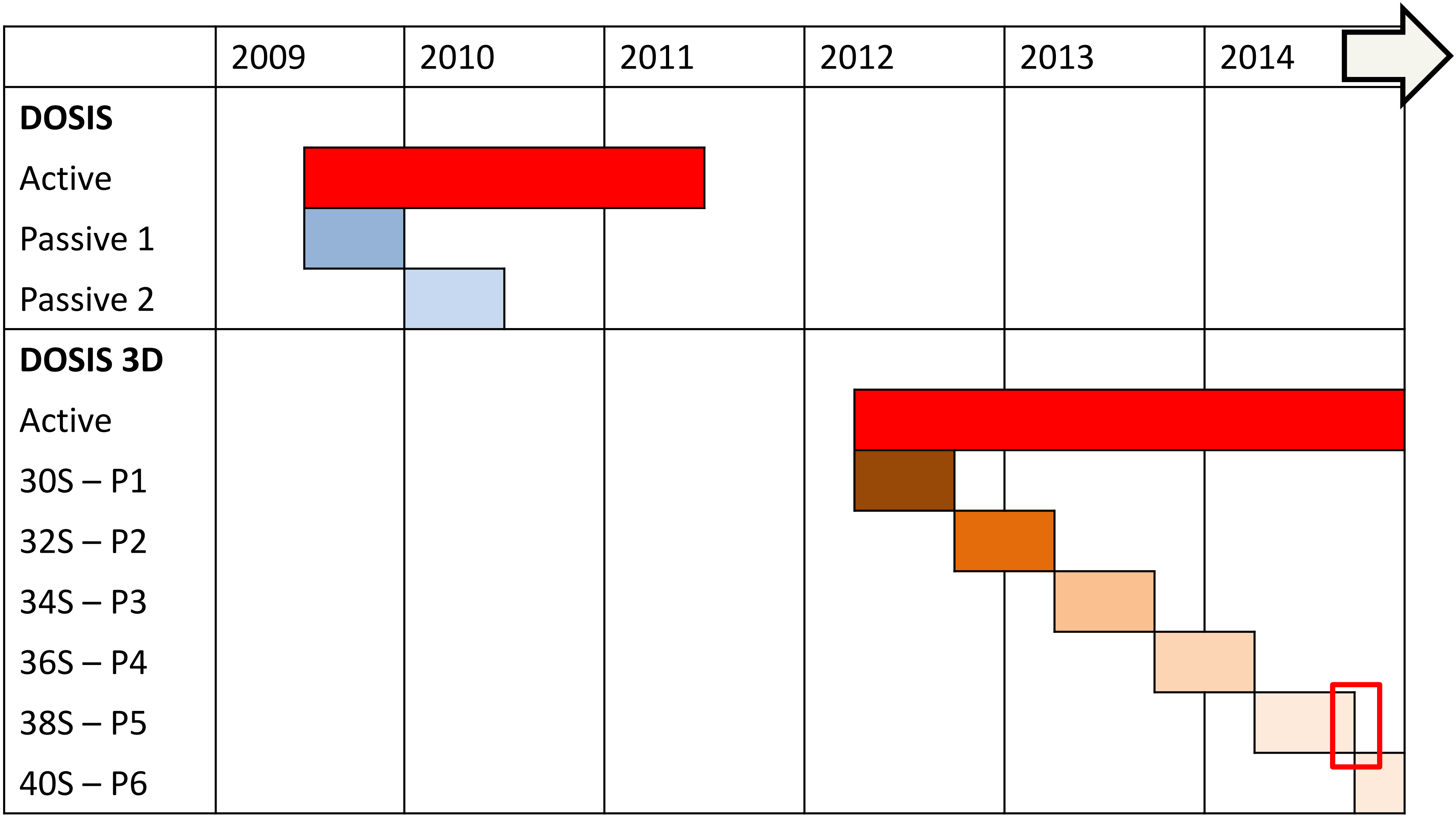
DOSIS & DOSIS 3D: Timeline



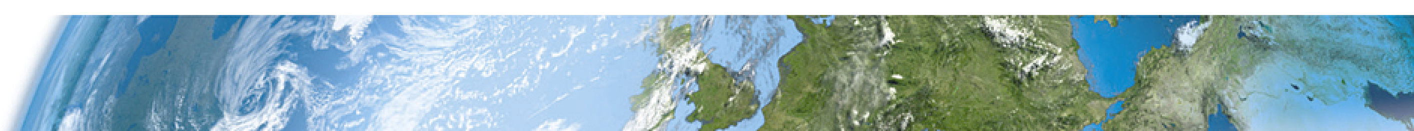
DOSIS & DOSIS 3D: Timeline



DOSIS & DOSIS 3D: Timeline → Active

Experiment	Detector	Timeline		Measurement period	Data [days]	ISS altitude [km]
DOSIS	DOSTEL-1	Launch (STS-127)	July 15, 2009	July 18, 2009 - May 28, 2010	**290**	337-350
		Installation	July 18, 2009			
		Activation	July 18, 2009			
		Retrieval	April 21, 2011			
		Return (Soyuz-25S)	May 24, 2011			
	DOSTEL-2	Launch (STS-127)	July 15, 2009	July 18, 2009 - June 16, 2011	**645**	337-375
		Installation	July 18, 2009			
		Activation	July 18, 2009			
		Retrieval	June 17,2011			
		Return (STS-135)	July 21, 2011			
DOSIS 3D	DOSTEL-1	Launch (Soyuz-30S)	May 15, 2012	May 21, 2012 – July 21, 2014	**732**	398-418
	DOSTEL-2	Installation	May 21, 2012	May 21, 2012 – July 17, 2014	**716**	
		Activation	May 21, 2012			

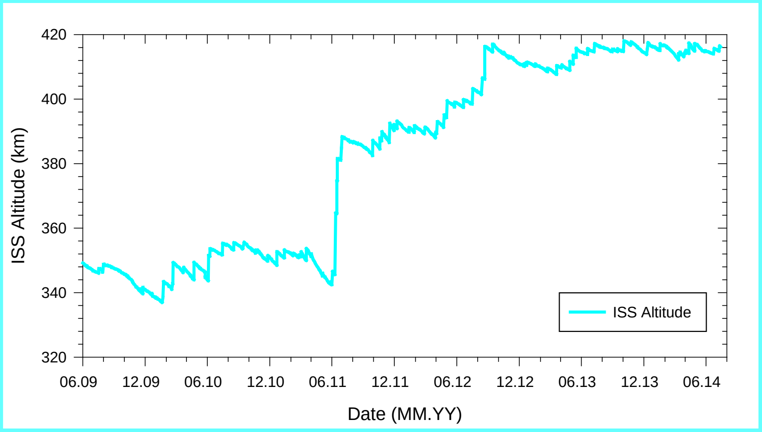
DLR

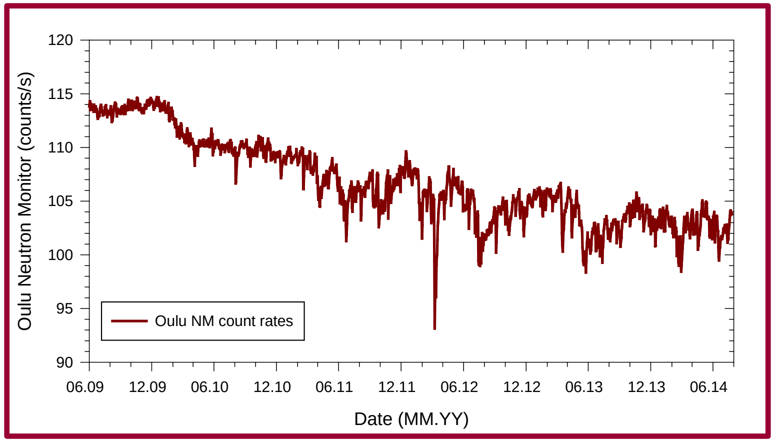


DOSIS & DOSIS 3D: Timeline → Passive

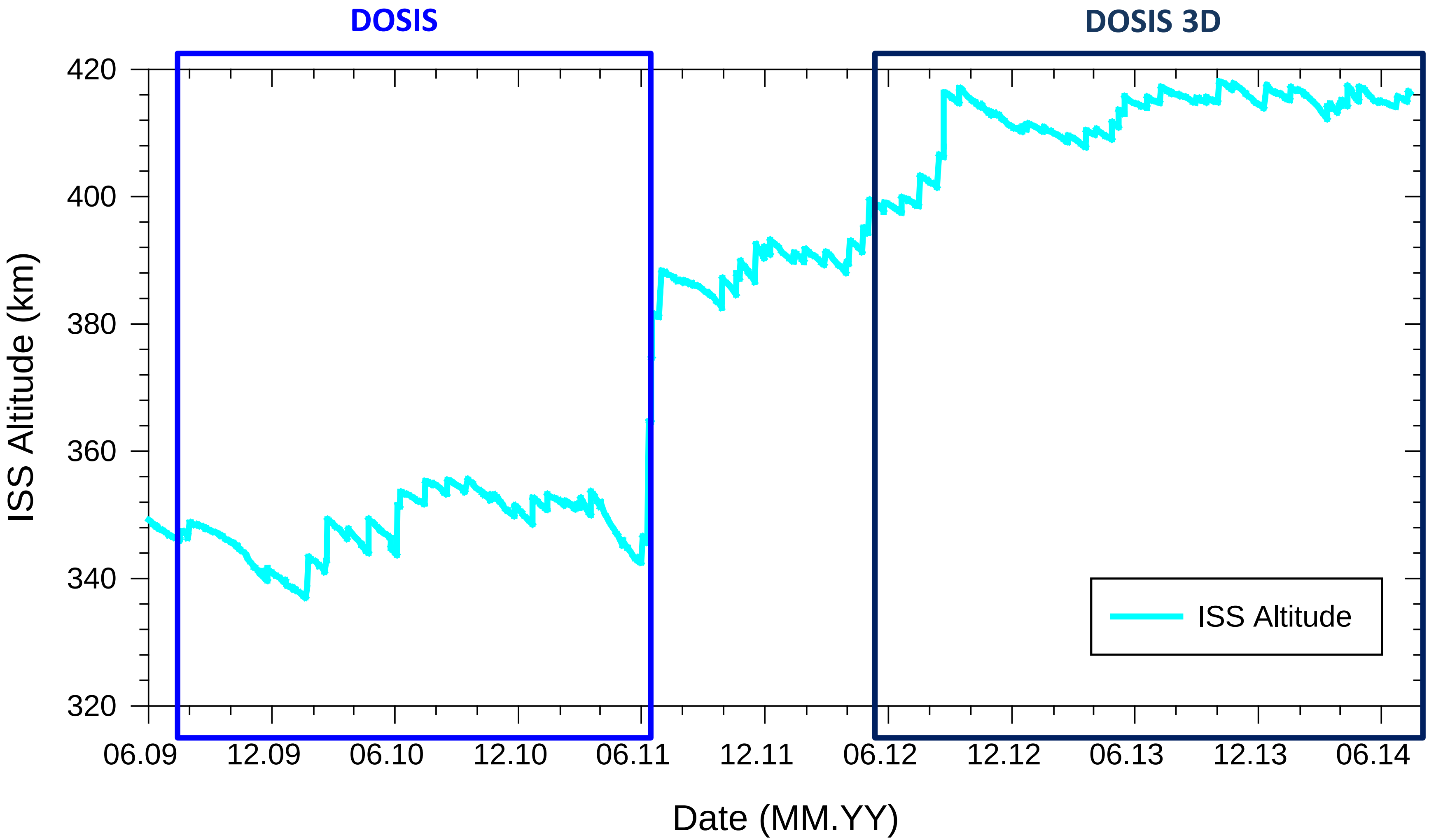
Experiment	Phase	Timeline		Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS	1	Launch (STS-127) Installation Retrieval Return (STS-129)	July 15, 2009 July 18, 2009 November 21, 2009 November 27, 2009	136	**127**	93	339-348
	2	Launch (STS-129) Installation Retrieval Return (STS-132)	November 16, 2009 November 21, 2009 May 18, 2010 May 26, 2010	191	**178**	93	337-349
DOSIS 3D	1	Launch (Soyuz 30S) Installation Retrieval Return (Soyuz 30S)	May 15, 2012 May 21, 2012 September 11, 2012 September 17, 2012	125	**113**	90	397-417
	2	Launch (Soyuz 32S) Installation Retrieval Return (Soyuz 32S)	October 23, 2012 October 27, 2012 March 13, 2013 March 16, 2013	144	**137**	95	407-416
	3	Launch (Soyuz 34S) Installation Retrieval Return (Soyuz 34S)	March 28, 2013 April 03, 2013 September 06, 2013 September 11, 2013	167	**156**	93	409-417
	4	Launch (Soyuz 36S) Installation Retrieval Return (Soyuz 36S)	September 25, 2013 October 01, 2013 March 06, 2014 March 11, 2014	167	**156**	93	413-418

DOSIS & DOSIS 3D: ISS Altitude and Solar Cycle

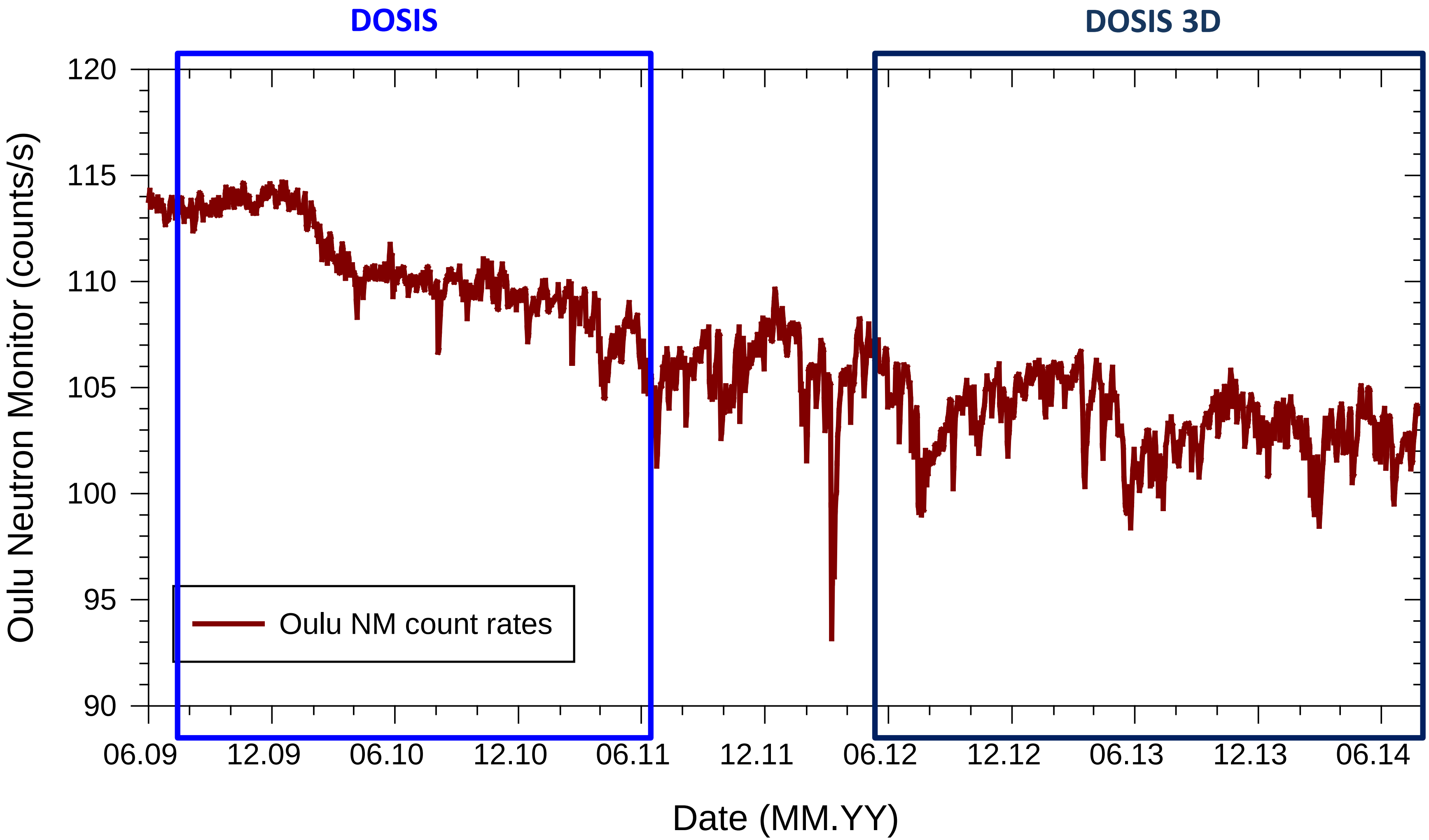




DOSIS & DOSIS 3D: ISS Altitude

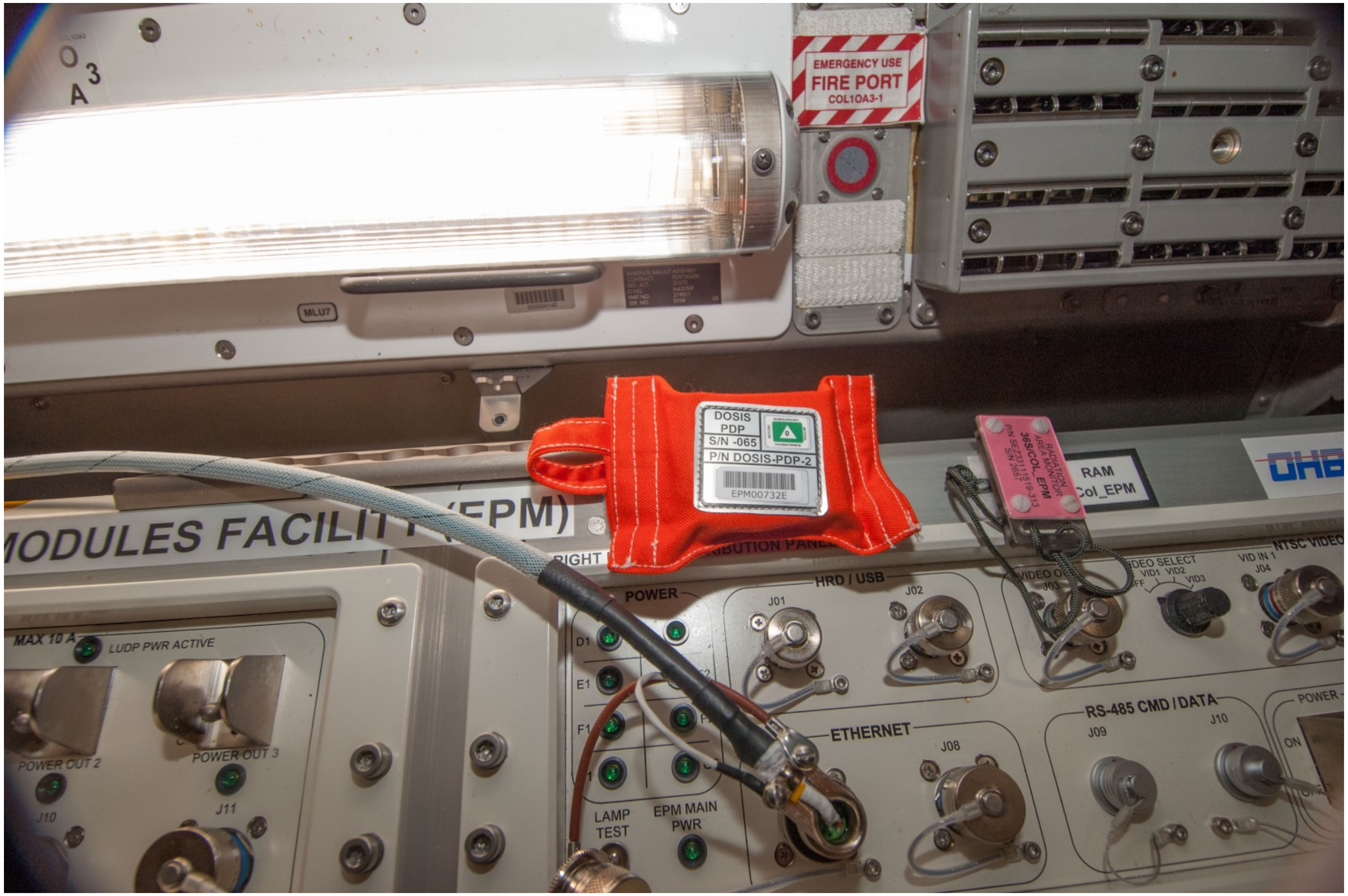


DOSIS & DOSIS 3D: Neutron Monitor Count rates



We acknowledge the NMDB database (**www.nmdb.eu**),founded under the European Union's (EC) FP7 programme (contract no. 213007) for providing data.

DOSIS & DOSIS 3D: PDP – Results 1



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DOSIS & DOSIS 3D: PDP → Results 1

Experiment	Phase	Timeline		Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS	**1**	Launch (STS-127) Installation Retrieval Return (STS-129)	July 15, 2009 July 18, 2009 November 21, 2009 November 27, 2009	136	**127**	93	339-348
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	3	Launch (Soyuz 34S) Installation Retrieval Return (Soyuz 34S)	March 28, 2013 April 03, 2013 September 06, 2013 September 11, 2013	167	**156**	93	409-417
	4	Launch (Soyuz 36S) Installation Retrieval Return (Soyuz 36S)	September 25, 2013 October 01, 2013 March 06, 2014 March 11, 2014	167	**156**	93	413-418

DOSIS & DOSIS 3D: PDP → Results 1

Experiment	Phase	Timeline		Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS	**1**	Launch (STS-127) Installation Retrieval Return (STS-129)	July 15, 2009 July 18, 2009 November 21, 2009 November 27, 2009	136	**127**	93	339-348
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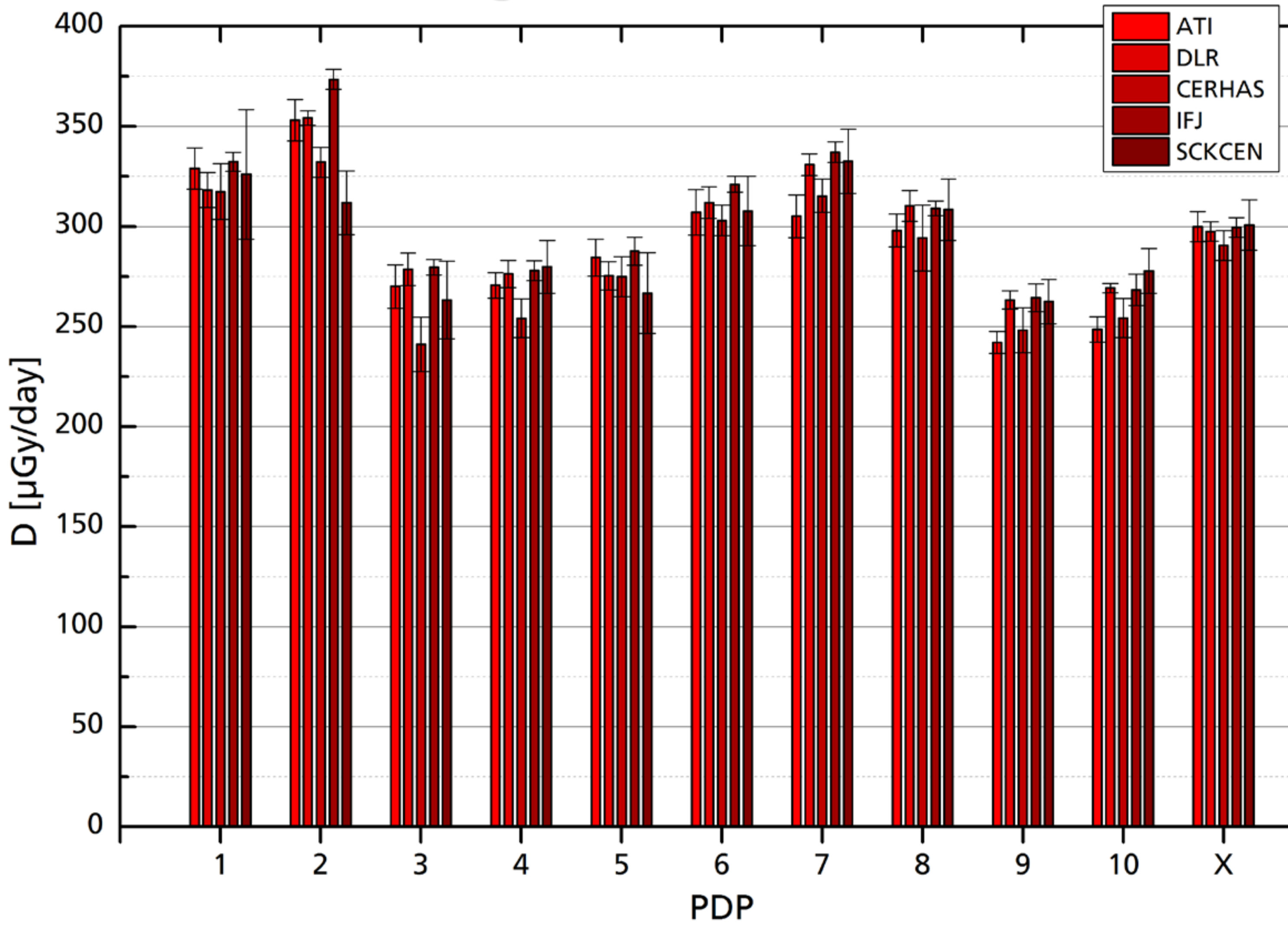
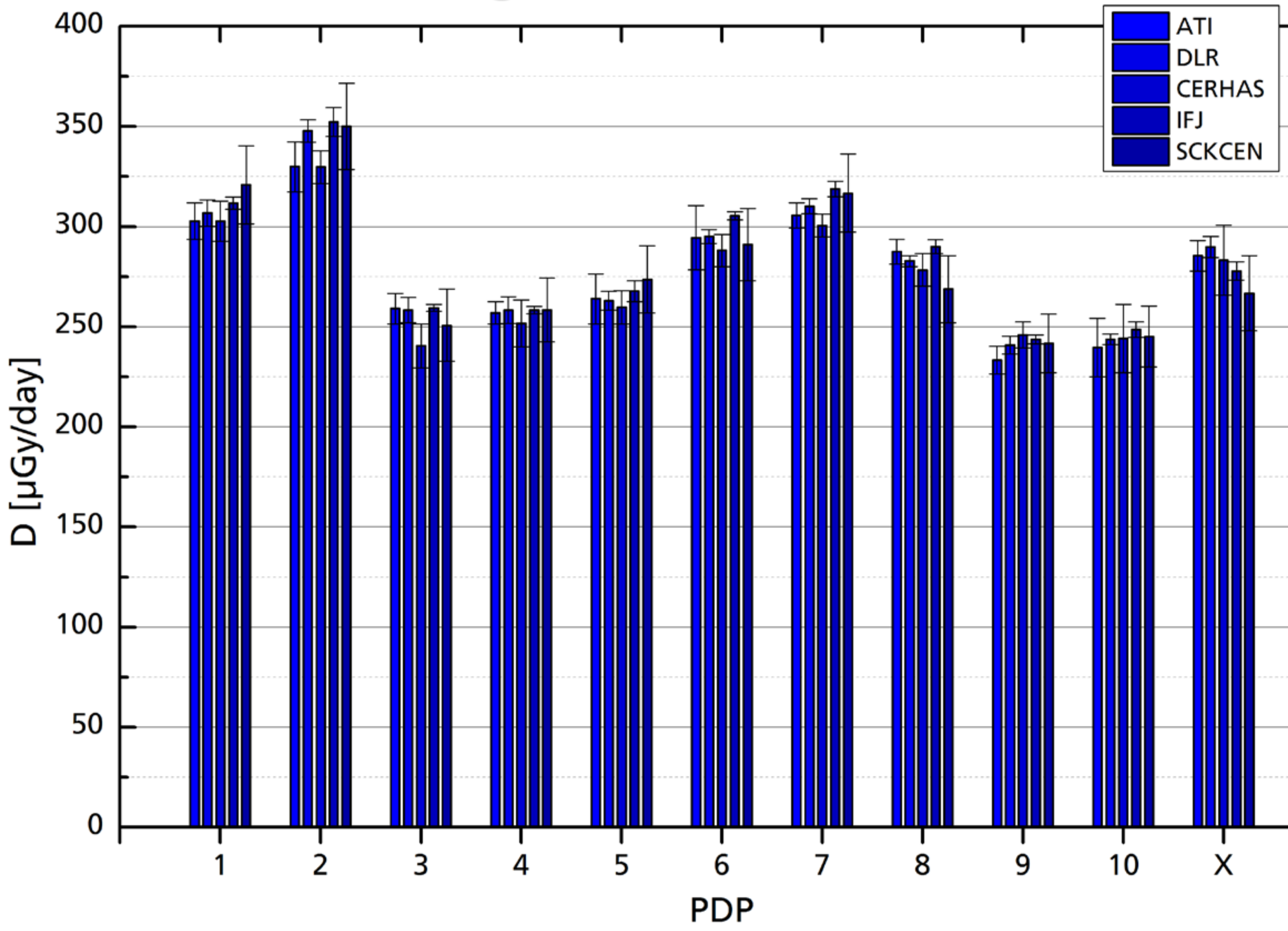
DOSIS & DOSIS 3D: TLD Read Out Systems & Detectors

Institute	TLD Name	Read out system	Heating Rate	Material	Pre Heat	Annealing Cycle	Cooling Rate	Calibration Method	Calibration source	Glow curve evaluation
DLR	**TLD 600** **TLD 700** **TLD 300**	**Harshaw 5500** (Hamamatsu RC095 HA)	5°C/s	LiF:Mg,Ti CaF_2:Tm	no pre heat no pre heat	400°C (1h), 100°C (2h) 400°C (1h), 100°C (2h)	slow slow	The same single-chip	^{137}Cs	Peak 5 height Peak 5 height
ATI	**TLD 600** **TLD 700** **TLD 300**	**TL-DAT.II** (THORN EMI 9635 QB)	5°C/s	LiF:Mg,Ti CaF_2:Tm	120°C (30min) no pre heat	400°C (1h) 400°C (1.5h)	slow slow	The same single-chip	^{60}Co	Peak 5 height Peak 5 height
IFJ	**MTS-6** **MTS-7** **MCP-7**	**RA'94** (THORN EMI 9789 QB) **Harshaw 3500** (ET 9125B)	10°C/s	LiF:Mg,Ti LiF:Mg,Cu,P	120°C (30min) 120°C (30min)	400°C (1h), 100°C (2h) 240°C (10min)	fast fast	Seperate group of TLDs	^{137}Cs	Peak integral Peak integral
SCK-CEN	**MTS-6** **MTS-7** **MCP-6** **MCP-7**	**Harshaw 5500** (Hamamatsu RC095 HA)	1°C/s	LiF:Mg,Ti LiF:Mg,Cu,P	no pre heat no pre heat	400°C (1h), 100°C (2h) 240°C (10min)	slow fast	The same single-chip	^{60}Co	Peak 5 Integration
CER-HAS	**MTS-6** **MTS-7**	**Harshaw 2000A-B,PC** (Thorn EMI 9235QA)	10°C/s	LiF:Mg,Ti	no pre heat	400°C (1h), 100°C (1h)	fast	The same single-chip	^{137}Cs	Peak 5 height
NIRS	**TLD 100**	**Harshaw5500** (Hamamatsu RC095 HA)	25°C/s	LiF:Mg,Ti	no pre heat	400°C (1h),100°C (2h)	slow	The same batch	^{137}Cs	
NASA	**TLD 100** **TLD 300**	**Harshaw 5500** (Hamamatsu RC095 HA)	6°C/s	LiF:Mg,Ti CaF_2:Tm	100°C (30min)	400°C (1h) 400°C (1h), 100°C (2h)	slow fast	The same batch	^{137}Cs	Peak 5 Integral
NPI	**Al_2O_3:C** **$CaSO_4$:Dy**	**RA'94** (THORN EMI 9789 QB) & **TOLEDO 654** TLD Reader	10°C/s	Al_2O_3:C $CaSO_4$:Dy	no pre heat 150°C (22s)	700°C (20min) 380°C (10min)	fast fast	The same single-chip	^{137}Cs	Glow curve integral

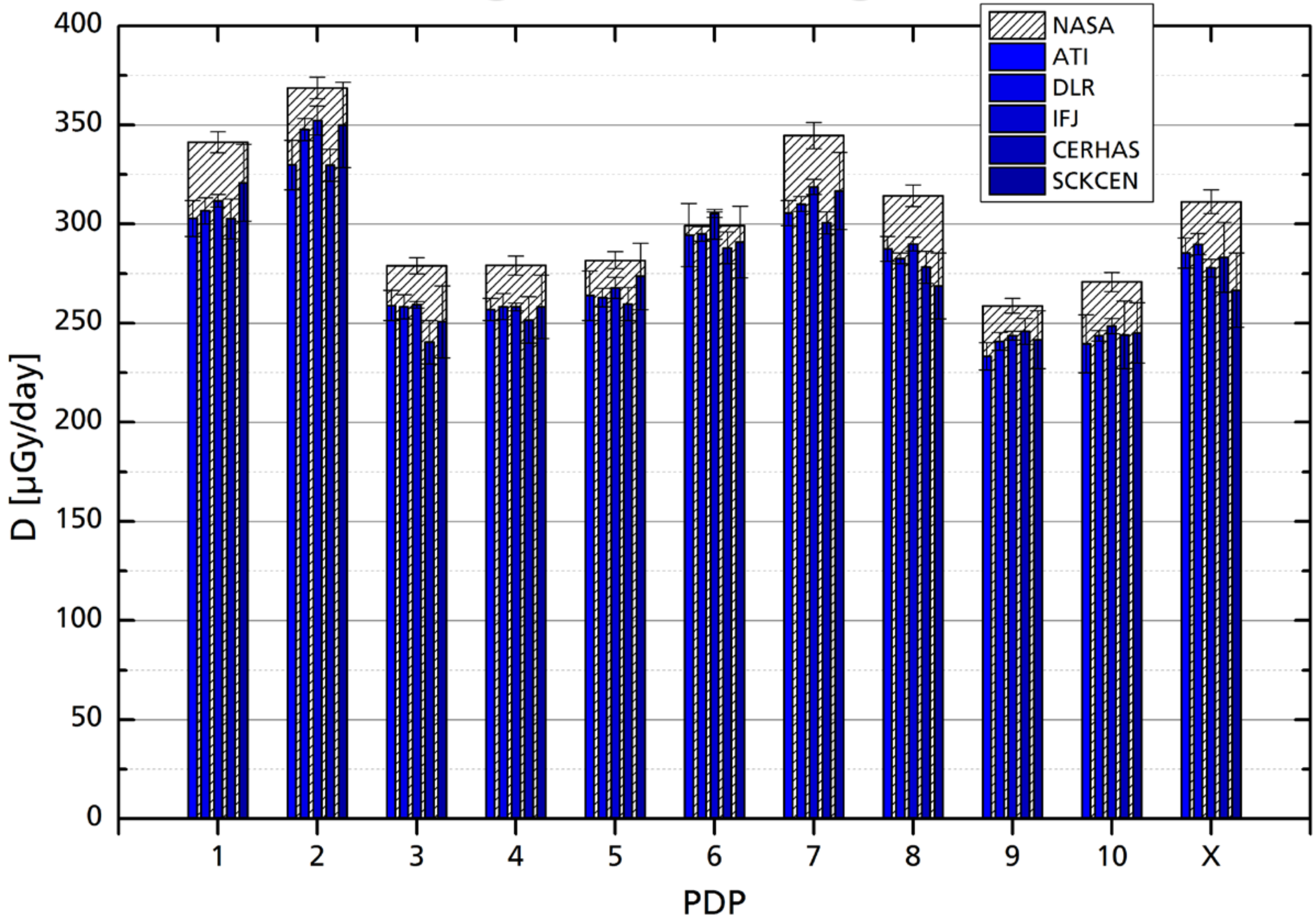
DOSIS 3D 2: ^{6}LiF:Mg,Ti



DOSIS 3D 2: ^{7}LiF:Mg,Ti



DOSIS 3D 2: ^{7}LiF:Mg,Ti + ^{Nat}LiF:Mg,Ti



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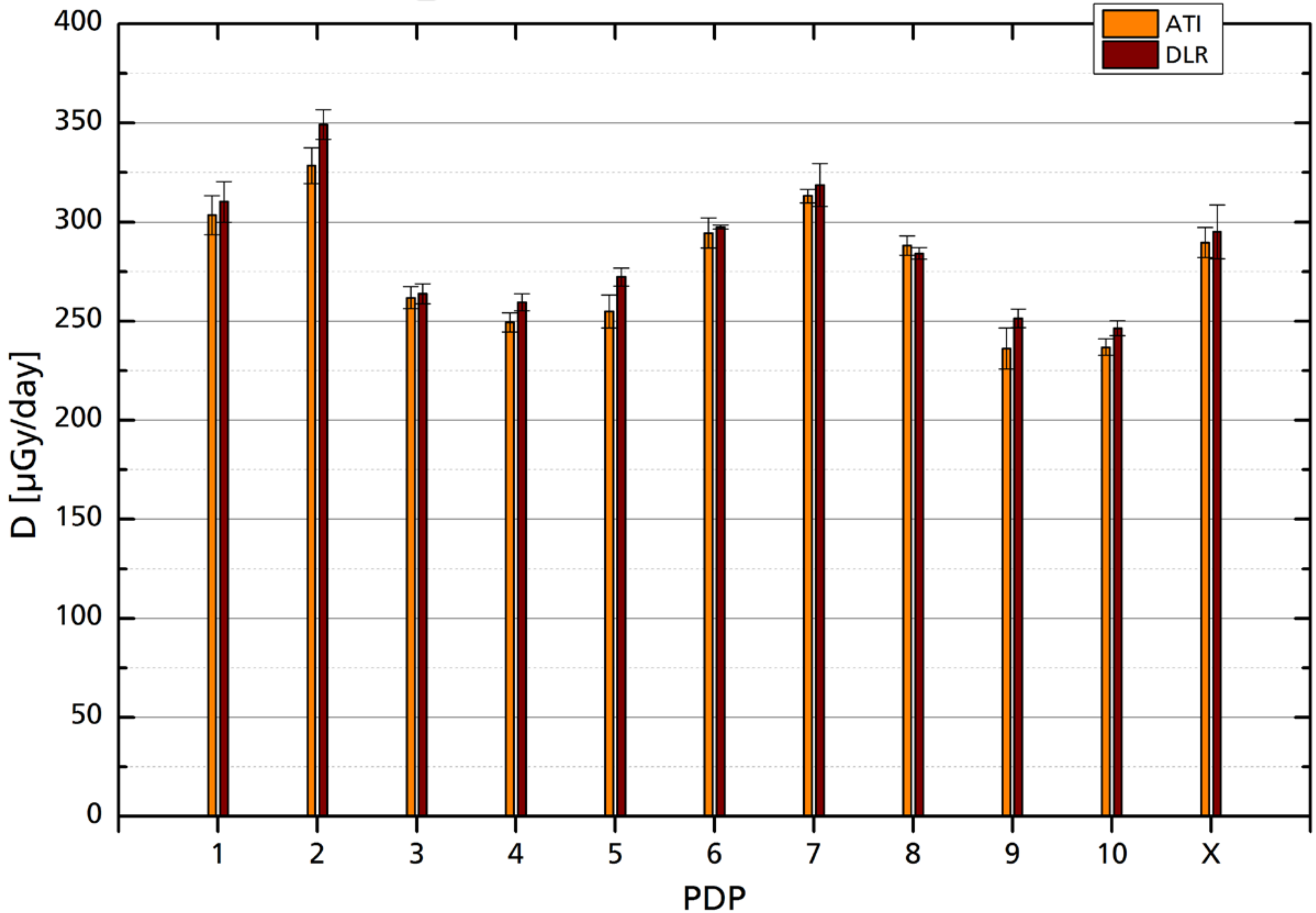
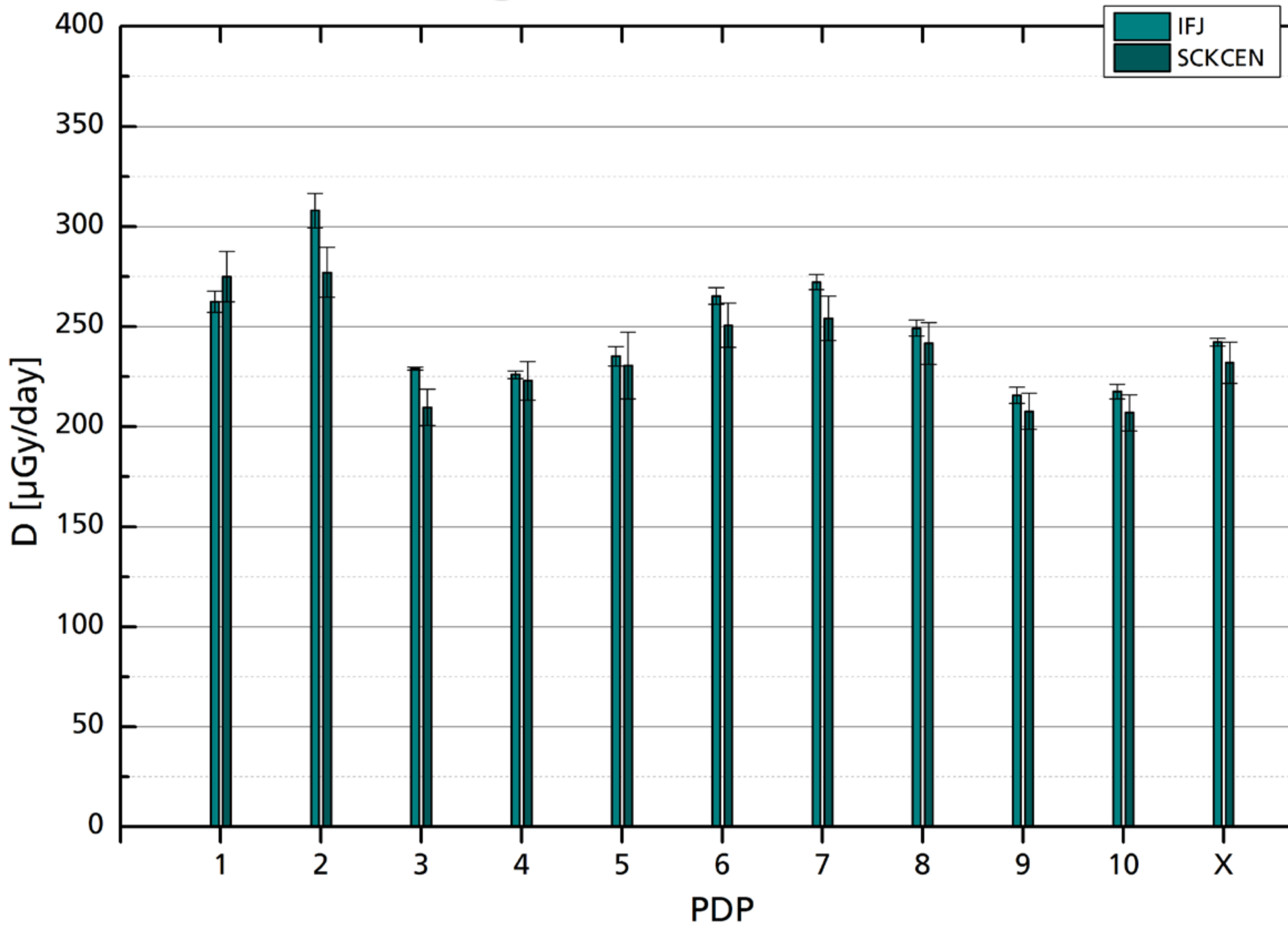
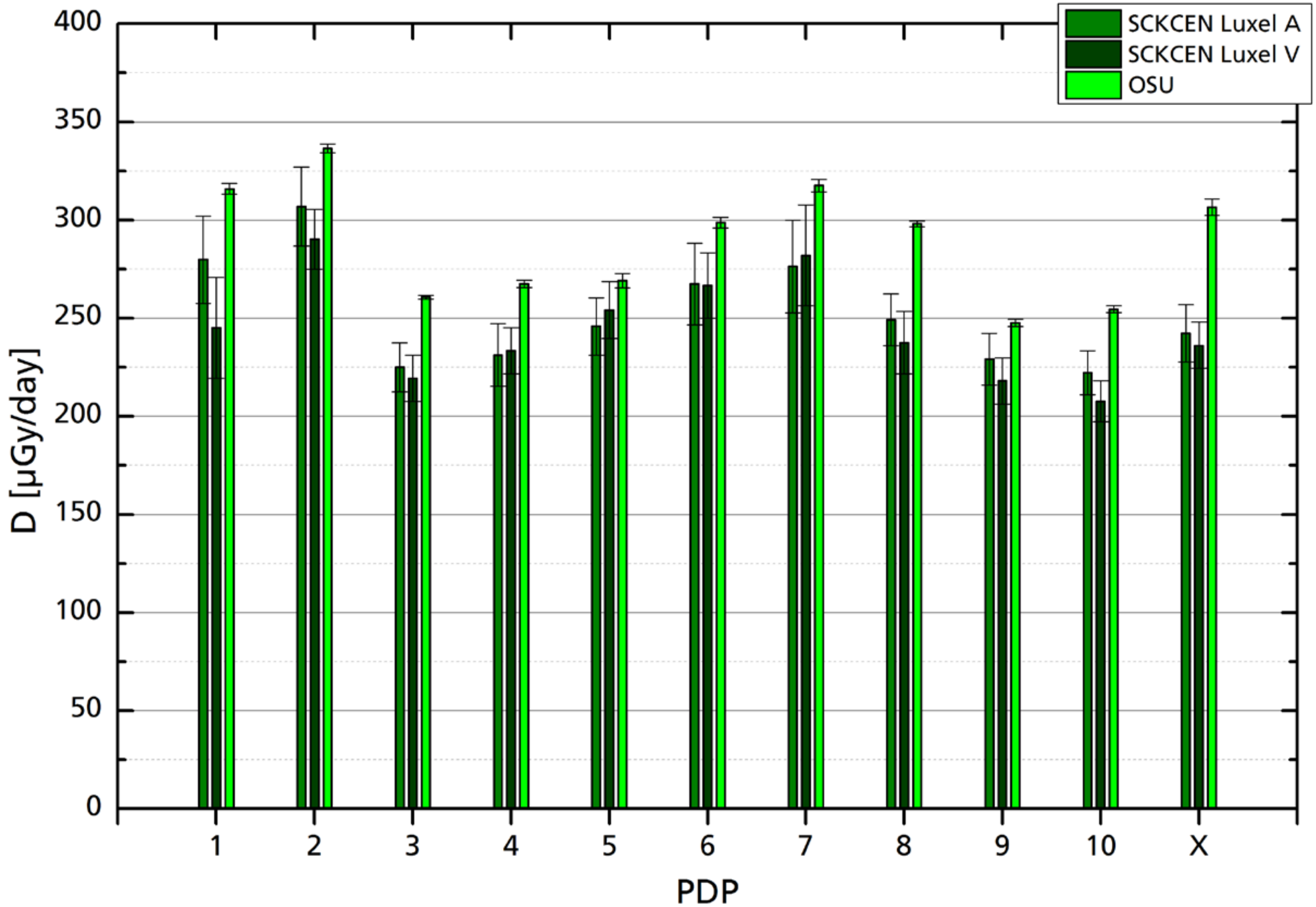
DOSIS 3D 2: CaF_2:Tm



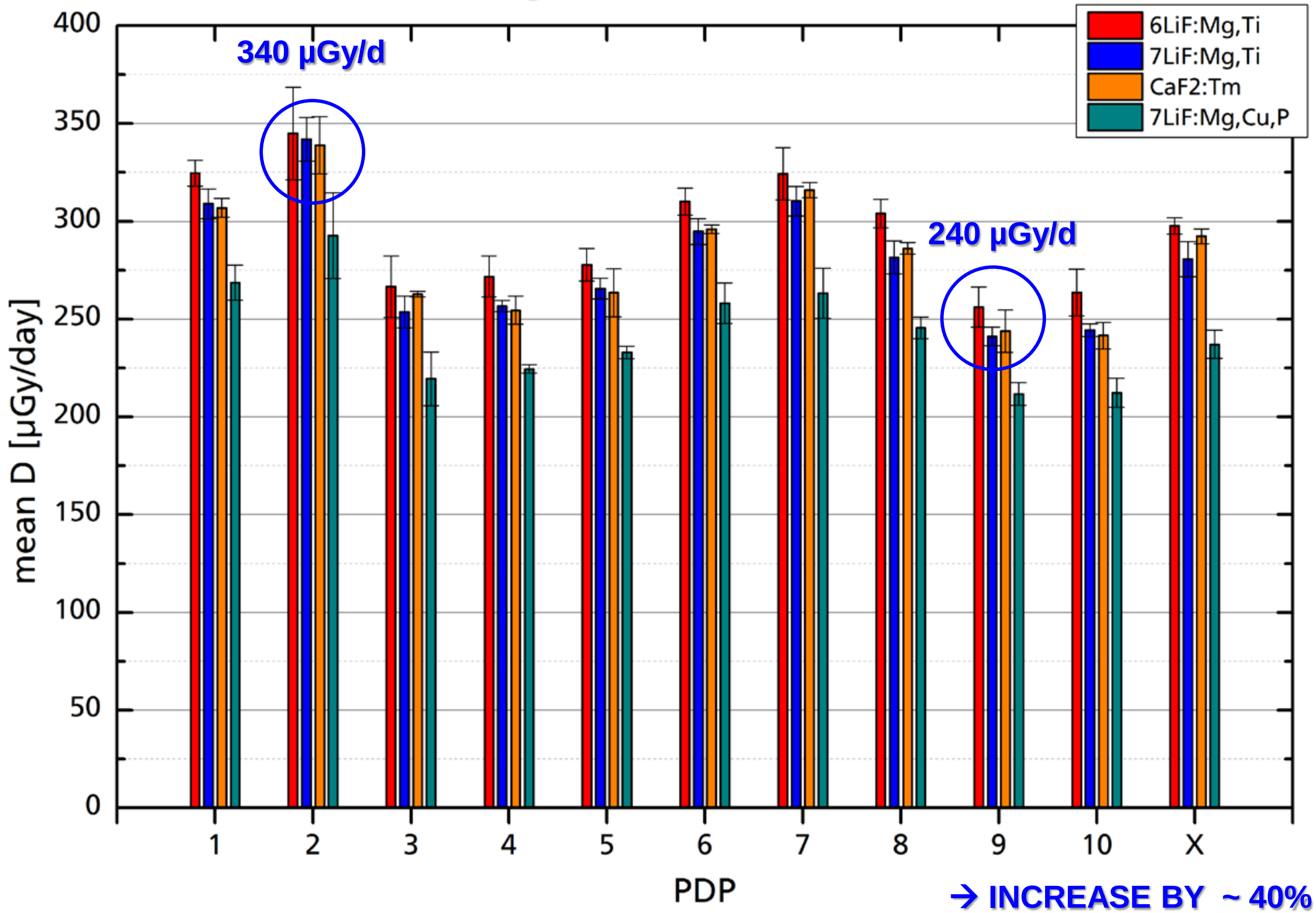
DOSIS 3D 2: $^{7}LiF:Mg,Cu,P$



DOSIS 3D 2: OSL

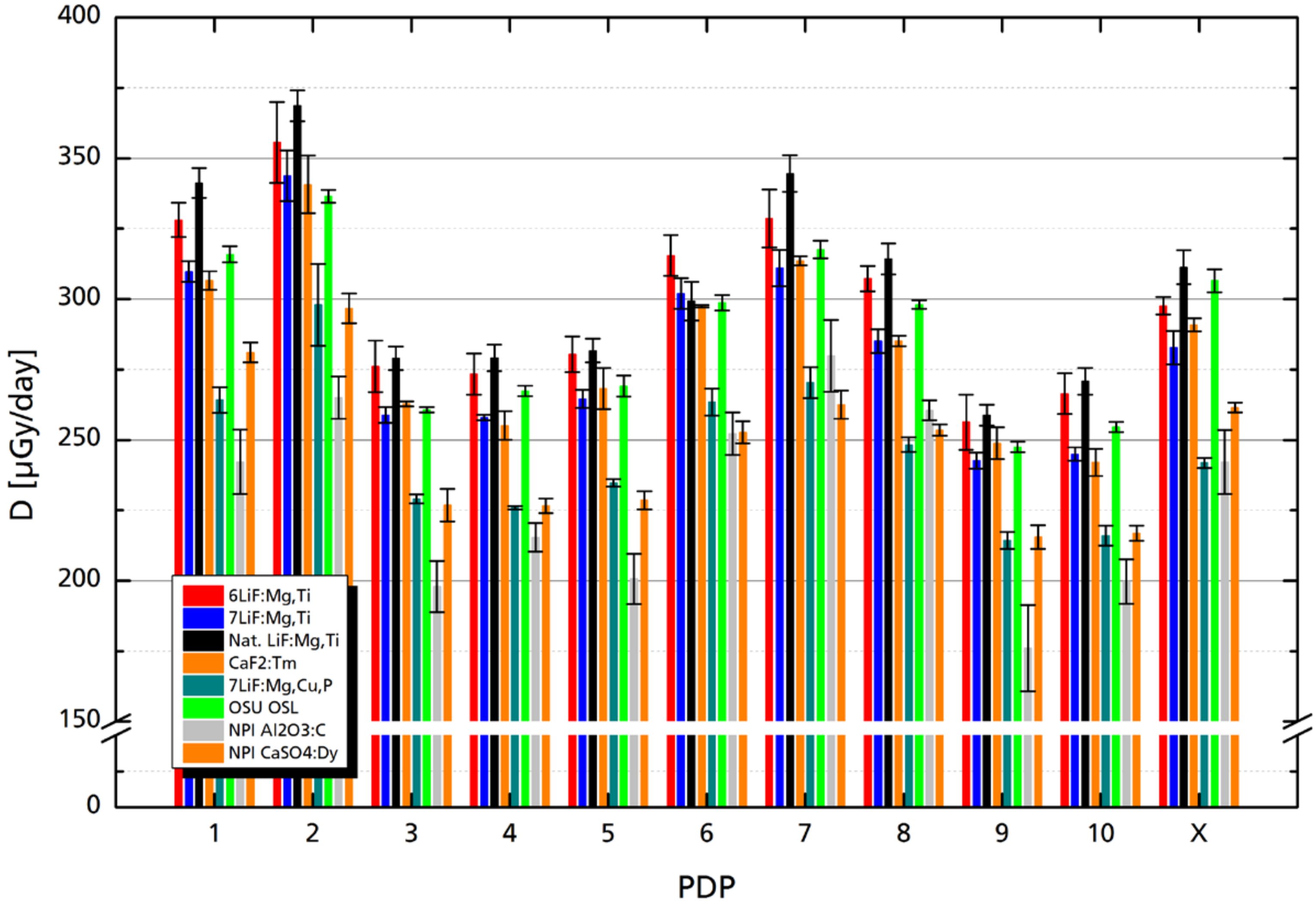


DOSIS 3D 2: Summary



→ INCREASE BY ~ 40%

DOSIS 3D 2: Summary



DOSIS 3D 2: Summary

- ^{6}LiF:Mg,Ti higher than ^{7}LiF:Mg,Ti → Neutrons
- ^{7}LiF:Mg,Ti higher than ^{7}LiF:Mg,Cu,P → LET Dependency
- CaF_2:Tm equal/higher than ^{7}LiF:Mg,Ti → LET Dependency
- OSL → Different Optical Filters (F and F+ centers)

Berger, T., Hajek, M., 2008. *TL-efficiency—Overview and experimental results over the years*. Radiation Measurements, 43, 146 – 156

Hajek, M., Berger, T., et al., 2008. *LET dependence of thermoluminescent efficiency and peak height ratio of CaF2:Tm*. Radiation Measurements, 43, 1135 – 1139

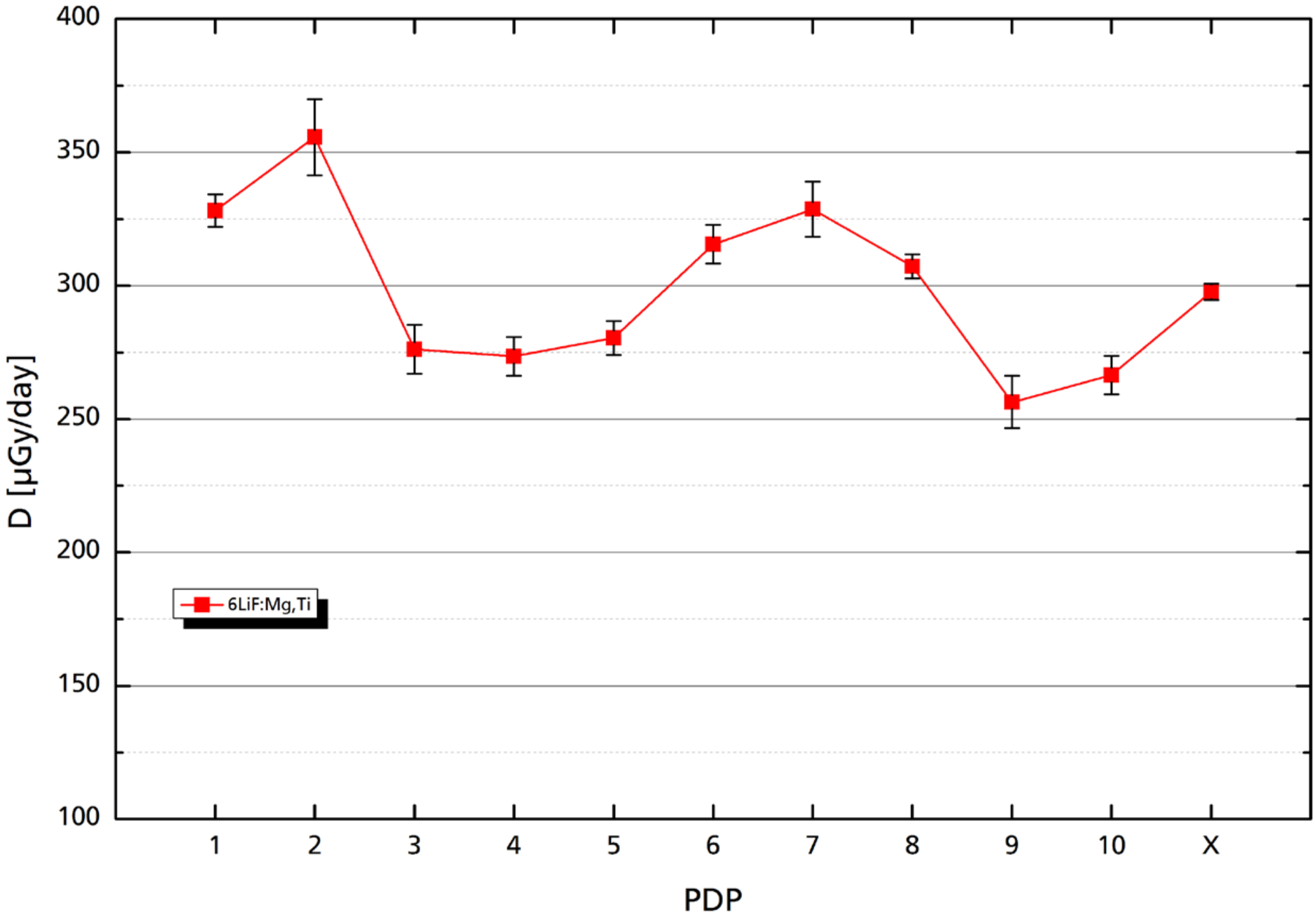
Bilski, P., Berger, T., Hajek, M., Reitz, G., 2011. *Comparison of the response of various TLDs to cosmic radiation and ion beams: current results of the HAMLET project.* Radiation Measurements, 46, 1680-1685

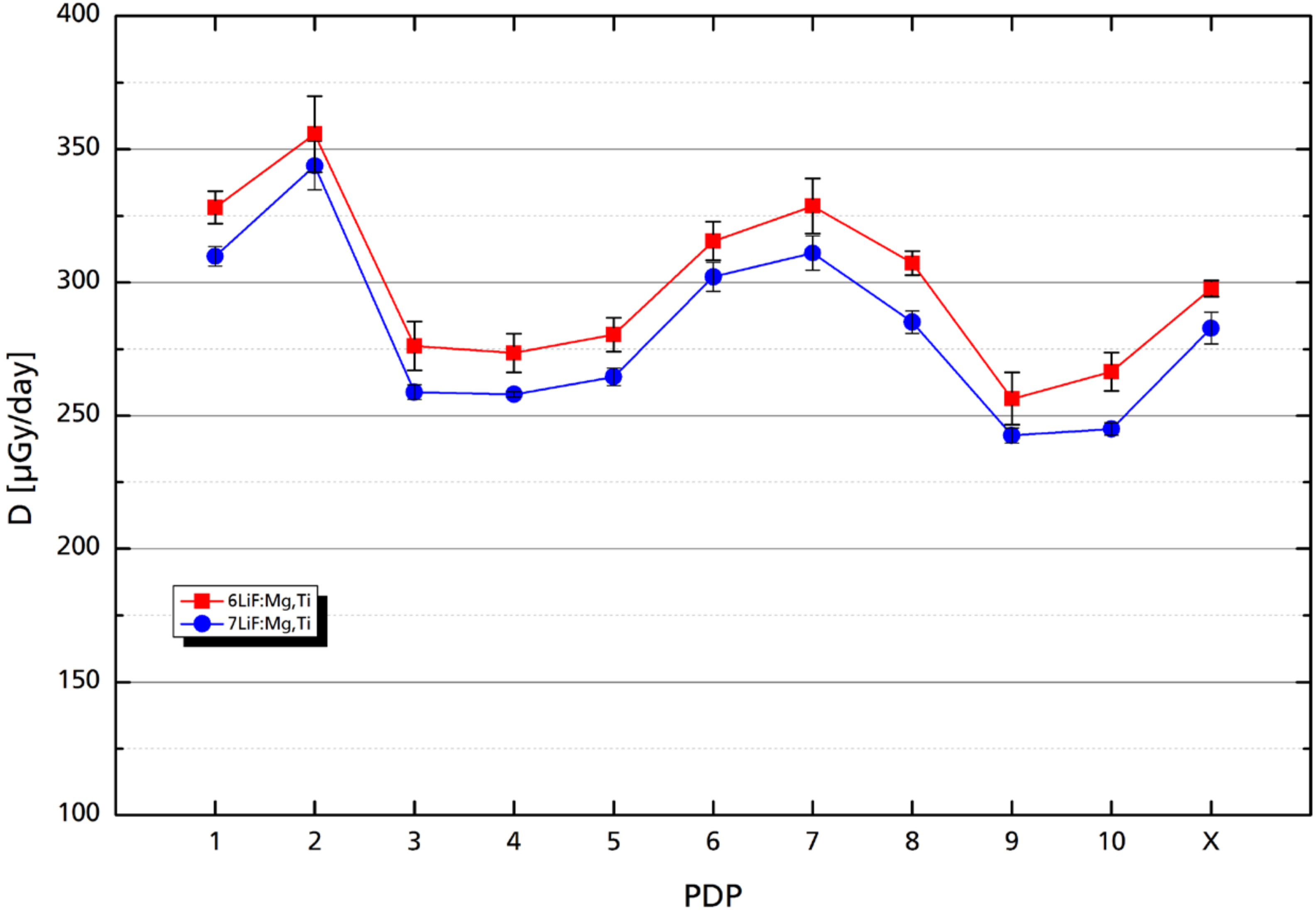
Bilski, P., 2011. *Calculation of the relative efficiency of thermoluminescent detectors to space radiation .* Radiation Measurements, 46, 1728-1731

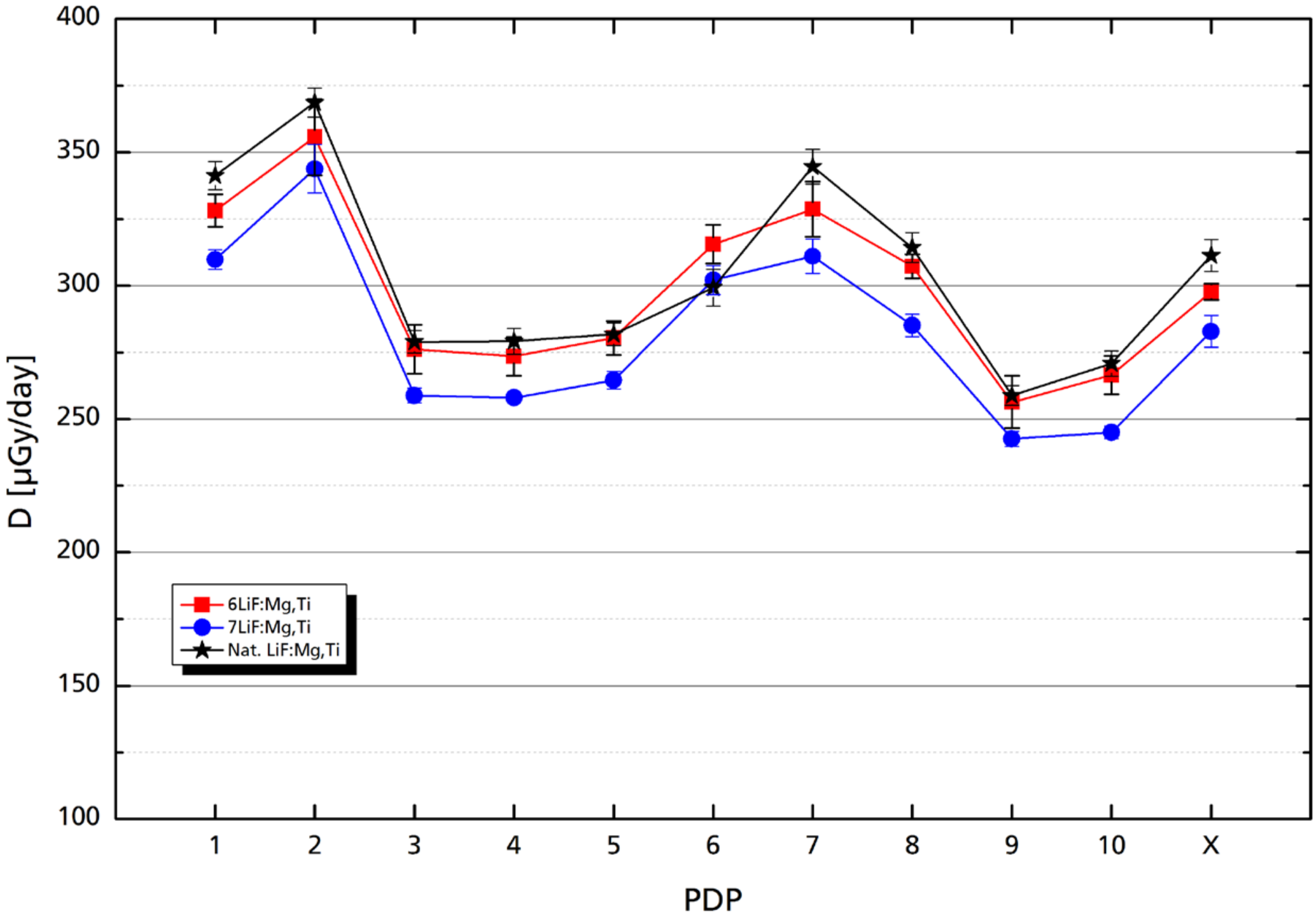
Burgkhardt B, Bilski P, Budzanowski M, Bottger R, Eberhardt K, Hampel G, et al. *Application of different TL detectors for the photon dosimetry in mixed radiation fields used for BNCT.* Radiat Prot Dosim 2006;120(1–4):83–6.

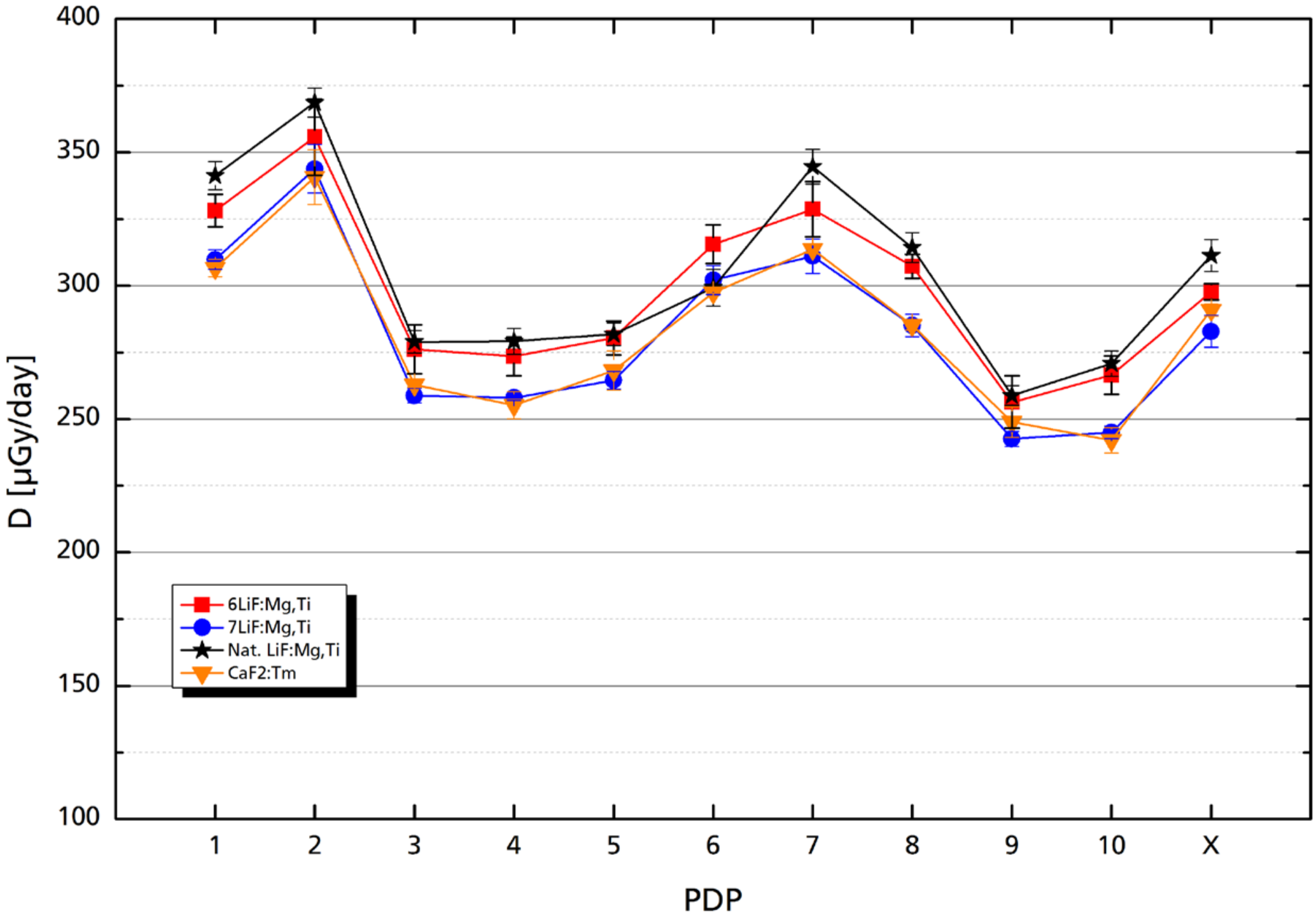
G. O. Sawakuchi, E. G. Yukihara, S. W. S. McKeever, E. R. Benton, R. Gaza, Y. Uchihori, N. Yasuda, and H. Kitamura *Relative optically stimulated luminescence and thermoluminescence efficiencies of Al2O3 :C dosimeters to heavy charged particles with energies relevant to space and radiotherapy dosimetry* JOURNAL OF APPLIED PHYSICS 104, 124903 2008

DOSIS 3D 2: Summary (BACKUP)


D [µGy/day]
400
350
300
250
200
150
100
1
2
3
4
5
6
7
8
9
10
X
PDP
6LiF:Mg,Ti


400
350
300
250
200
150
100
D [µGy/day]
6LiF:Mg,Ti
7LiF:Mg,Ti
1
2
3
4
5
6
7
8
9
10
X
PDP


400
350
300
250
200
150
100
D [µGy/day]
1
2
3
4
5
6
7
8
9
10
X
PDP
6LiF:Mg,Ti
7LiF:Mg,Ti
Nat. LiF:Mg,Ti



D [µGy/day]
400
350
300
250
200
150
100
1
2
3
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5
6
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9
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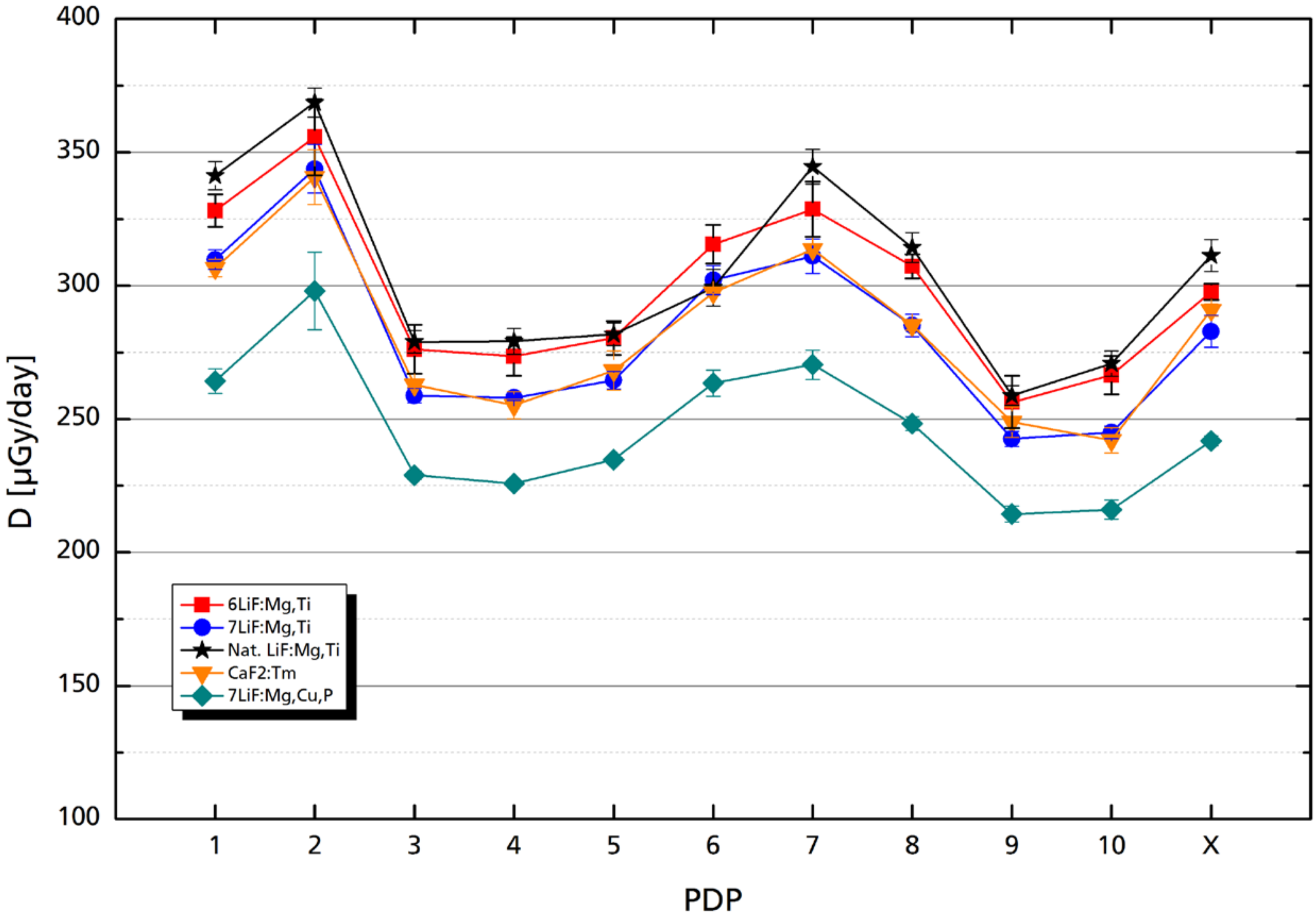
X
PDP
6LiF:Mg,Ti
7LiF:Mg,Ti
Nat. LiF:Mg,Ti
CaF2:Tm



400
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D [µGy/day]
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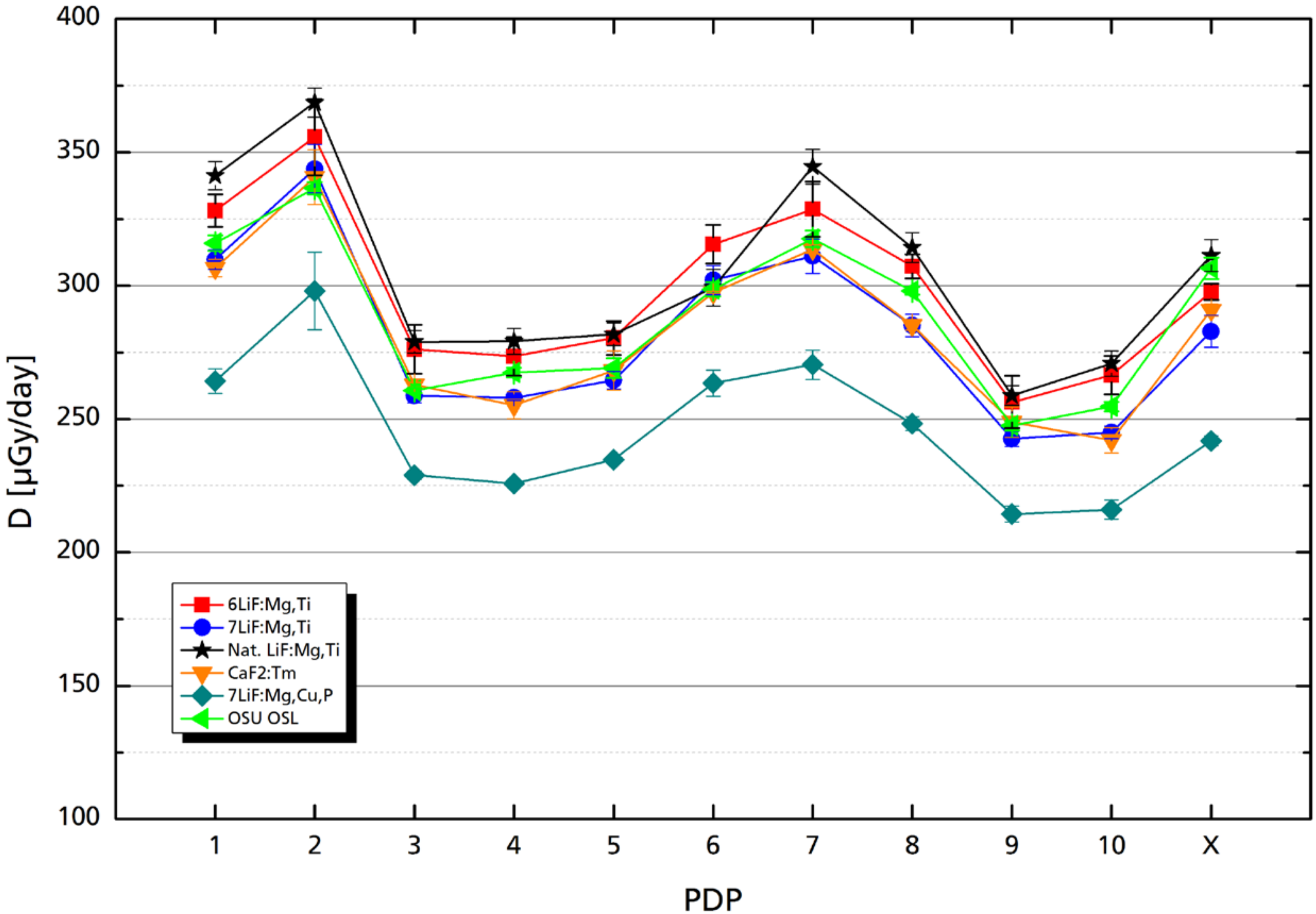
X
PDP
6LiF:Mg,Ti
7LiF:Mg,Ti
Nat. LiF:Mg,Ti
CaF2:Tm
7LiF:Mg,Cu,P



400
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D [µGy/day]
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4
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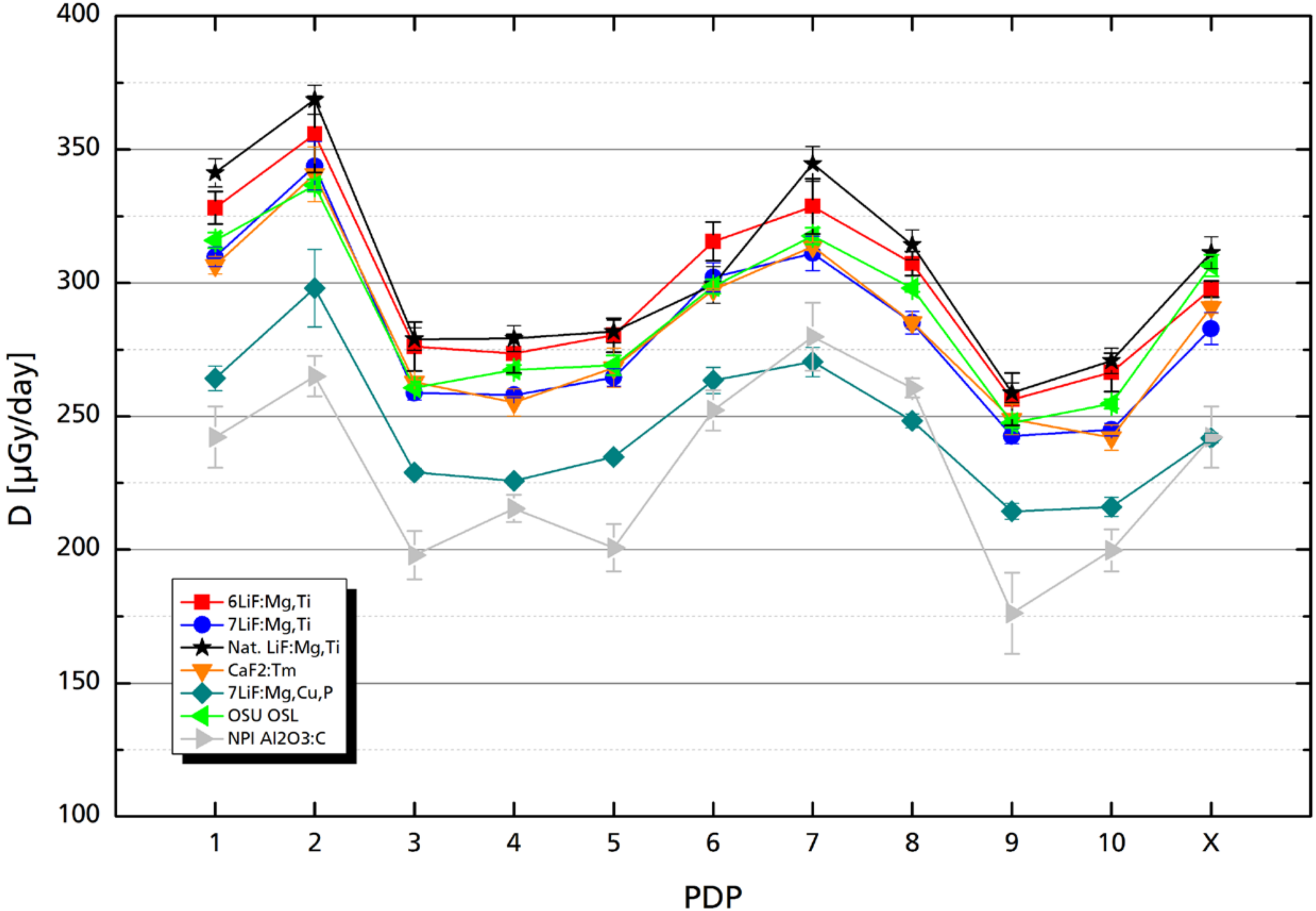
6
7
8
9
10
X
PDP
6LiF:Mg,Ti
7LiF:Mg,Ti
Nat. LiF:Mg,Ti
CaF2:Tm
7LiF:Mg,Cu,P
OSU OSL


DLR



D [µGy/day]
400
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300
250
200
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100
1
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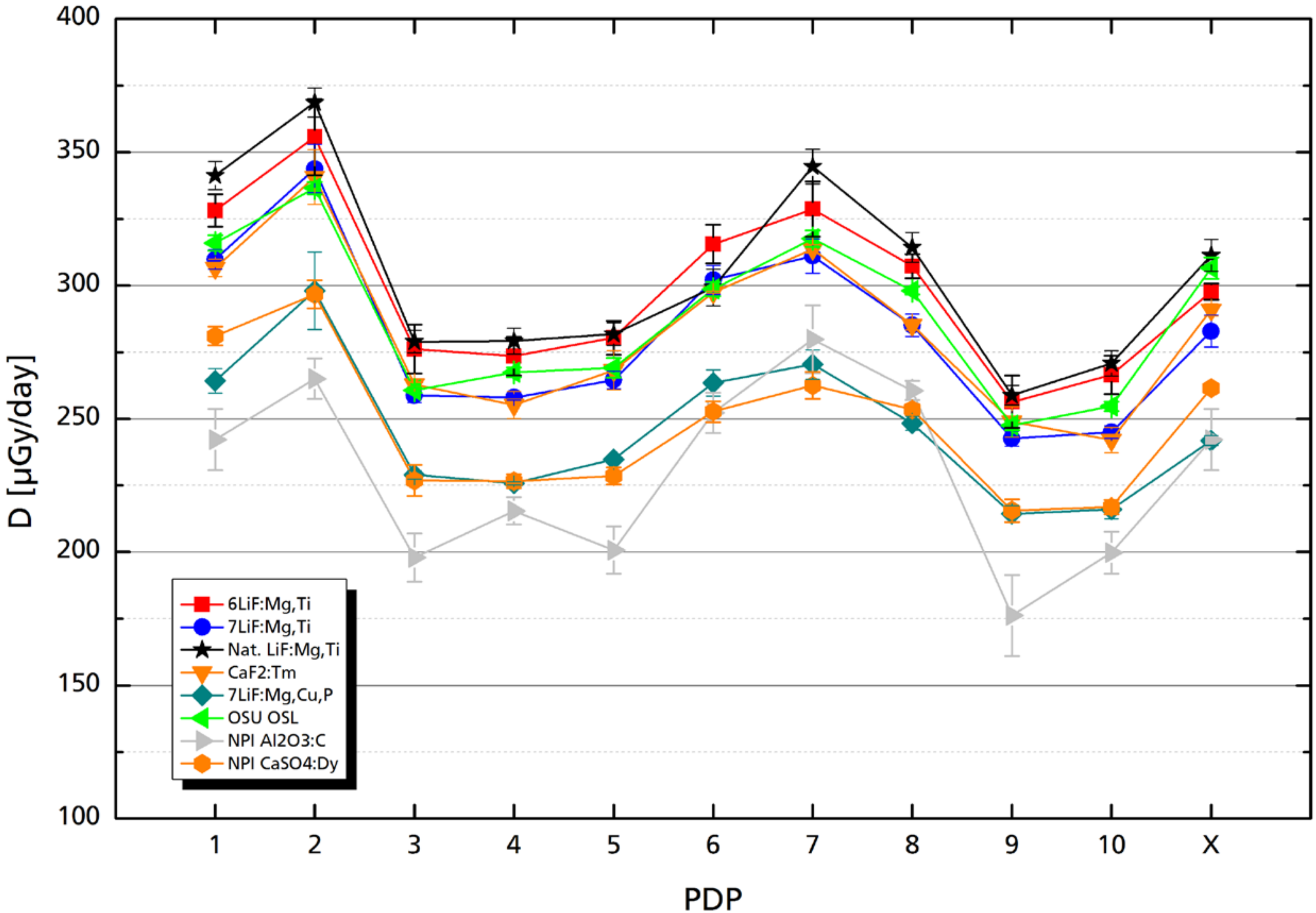
7
8
9
10
X
PDP
6LiF:Mg,Ti
7LiF:Mg,Ti
Nat. LiF:Mg,Ti
CaF2:Tm
7LiF:Mg,Cu,P
OSU OSL
NPI Al2O3:C

DLR



400
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D [µGy/day]
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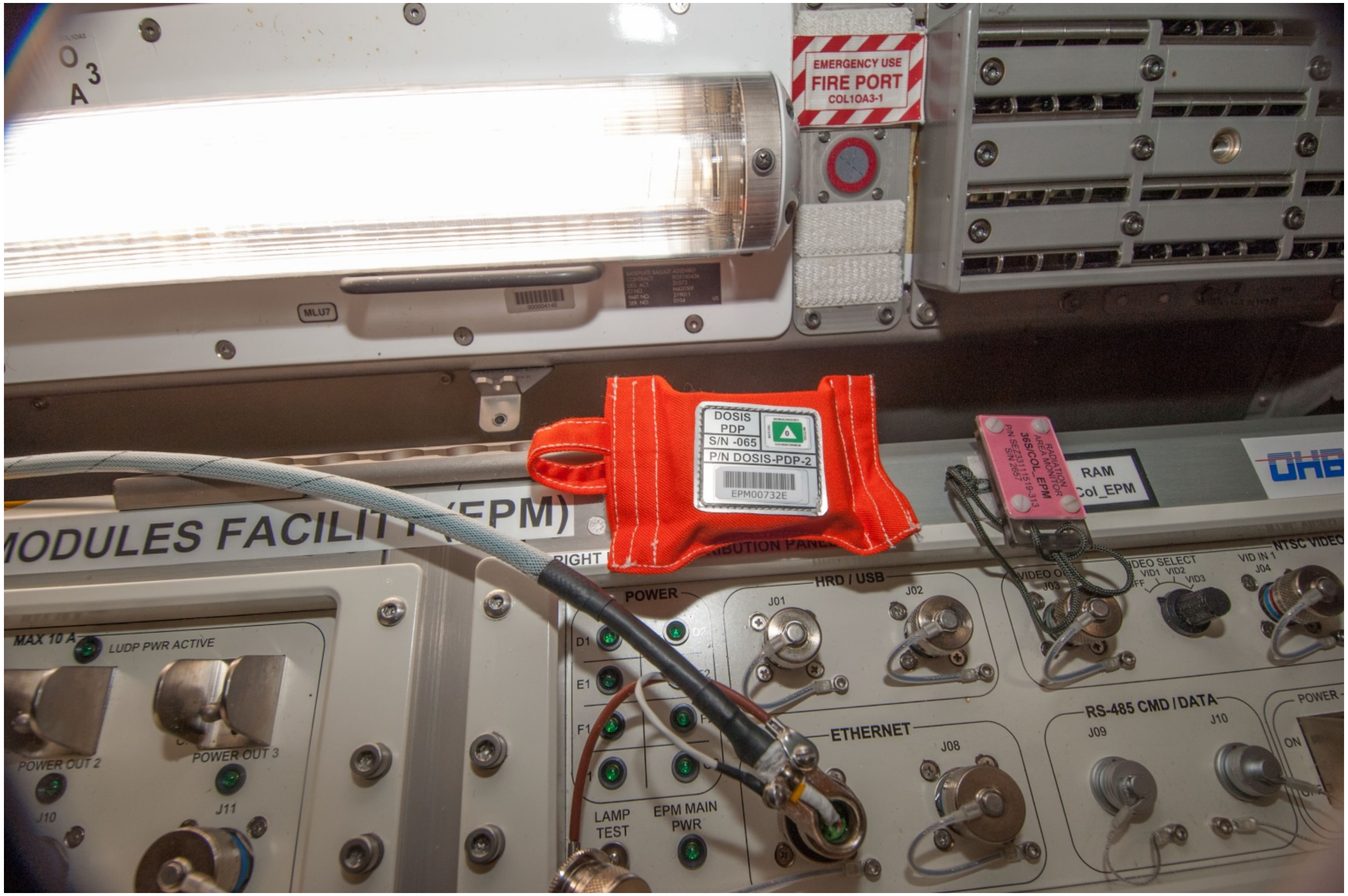
6
7
8
9
10
X
PDP
6LiF:Mg,Ti
7LiF:Mg,Ti
Nat. LiF:Mg,Ti
CaF2:Tm
7LiF:Mg,Cu,P
OSU OSL
NPI Al2O3:C
NPI CaSO4:Dy

DOSIS & DOSIS 3D: PDP – Results 2



DOSIS & DOSIS 3D: PDP – Results 2

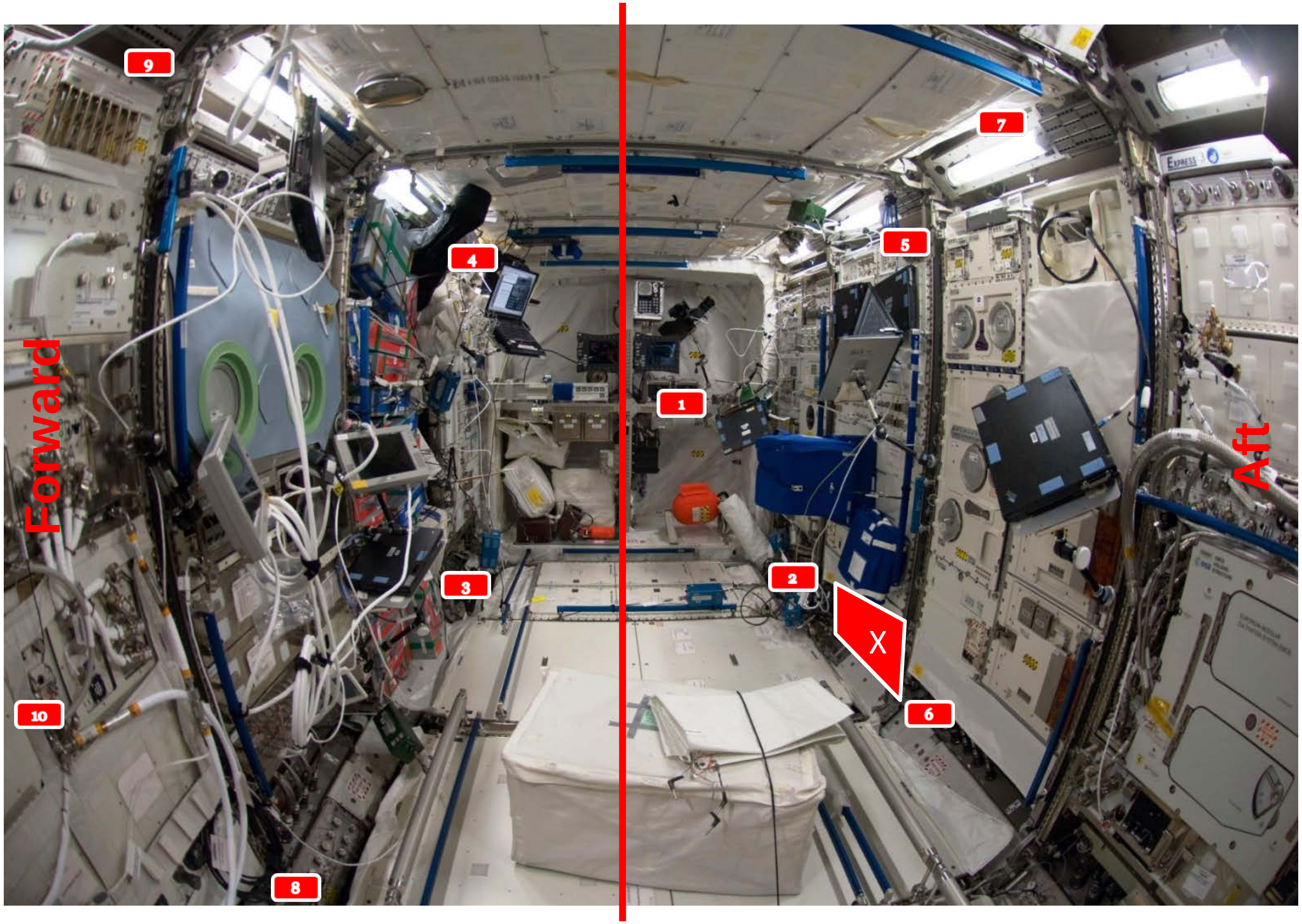
Experiment	Phase	Timeline		Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS	**1**	Launch (STS-127) Installation Retrieval Return (STS-129)	July 15, 2009 July 18, 2009 November 21, 2009 November 27, 2009	136	**127**	93	339-348
	2	Launch (STS-129) Installation Retrieval Return (STS-132)	November 16, 2009 November 21, 2009 May 18, 2010 May 26, 2010	191	**178**	93	337-349
DOSIS 3D	**1**	Launch (Soyuz 30S) Installation Retrieval Return (Soyuz 30S)	May 15, 2012 May 21, 2012 September 11, 2012 September 17, 2012	125	**113**	90	397-417
	2	Launch (Soyuz 32S) Installation Retrieval Return (Soyuz 32S)	October 23, 2012 October 27, 2012 March 13, 2013 March 16, 2013	144	**137**	95	407-416
	3	Launch (Soyuz 34S) Installation Retrieval Return (Soyuz 34S)	March 28, 2013 April 03, 2013 September 06, 2013 September 11, 2013	167	**156**	93	409-417
	4	Launch (Soyuz 36S) Installation Retrieval Return (Soyuz 36S)	September 25, 2013 October 01, 2013 March 06, 2014 March 11, 2014	167	**156**	93	413-418

DLR

DOSIS & DOSIS 3D: PDP – Results 2

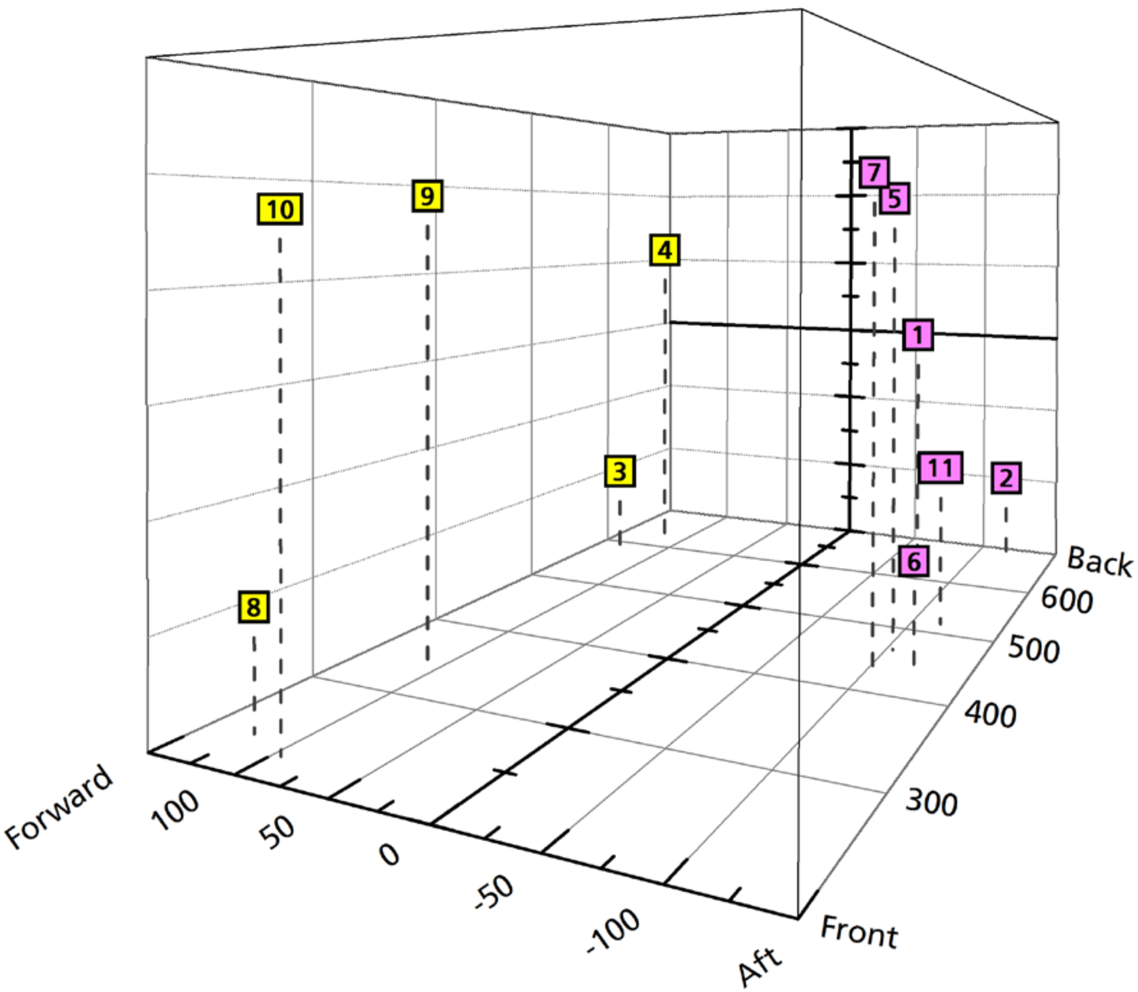
Experiment	Phase	Timeline		Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS	1	Launch (STS-127) Installation Retrieval Return (STS-129)	July 15, 2009 July 18, 2009 November 21, 2009 November 27, 2009	136	**127**	93	339-348
	2	Launch (STS-129) Installation Retrieval Return (STS-132)	November 16, 2009 November 21, 2009 May 18, 2010 May 26, 2010	191	**178**	93	337-349
DOSIS 3D	1	Launch (Soyuz 30S) Installation Retrieval Return (Soyuz 30S)	May 15, 2012 May 21, 2012 September 11, 2012 September 17, 2012	125	**113**	90	397-417
	2	Launch (Soyuz 32S) Installation Retrieval Return (Soyuz 32S)	October 23, 2012 October 27, 2012 March 13, 2013 March 16, 2013	144	**137**	95	407-416
	3	Launch (Soyuz 34S) Installation Retrieval Return (Soyuz 34S)	March 28, 2013 April 03, 2013 September 06, 2013 September 11, 2013	167	**156**	93	409-417
	4	Launch (Soyuz 36S) Installation Retrieval Return (Soyuz 36S)	September 25, 2013 October 01, 2013 March 06, 2014 March 11, 2014	167	**156**	93	413-418

DOSIS & DOSIS 3D: PDP – Results 2



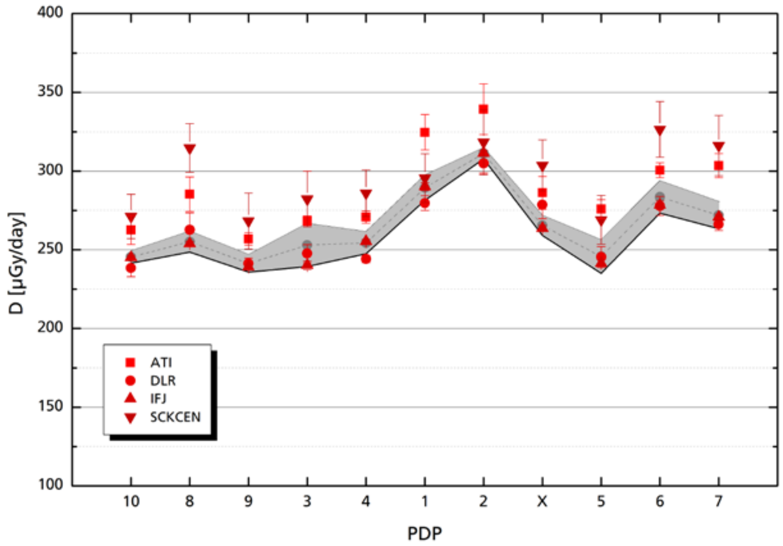
Cologne, Germany; Vienna, Austria; Krakow, Poland

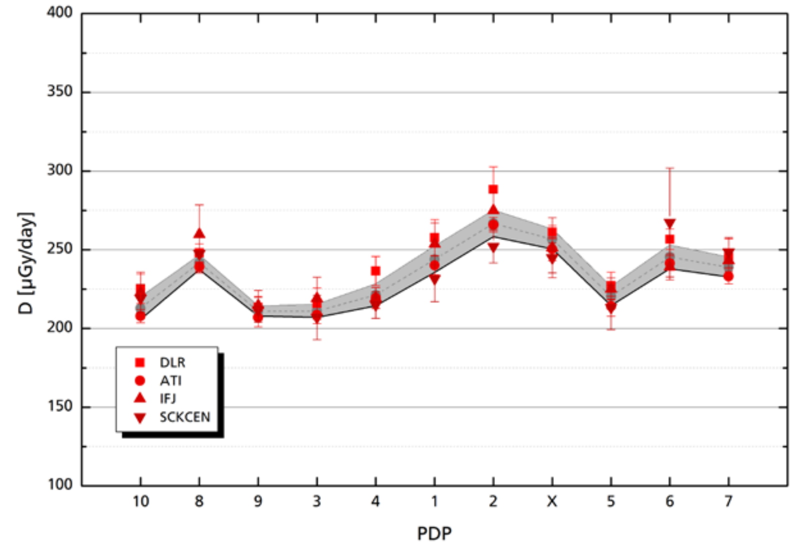
DOSIS & DOSIS 3D: PDP – Results 2

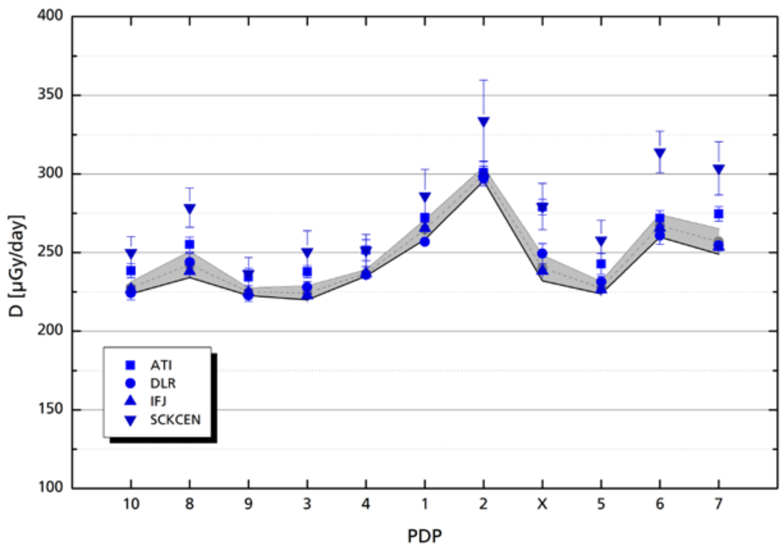


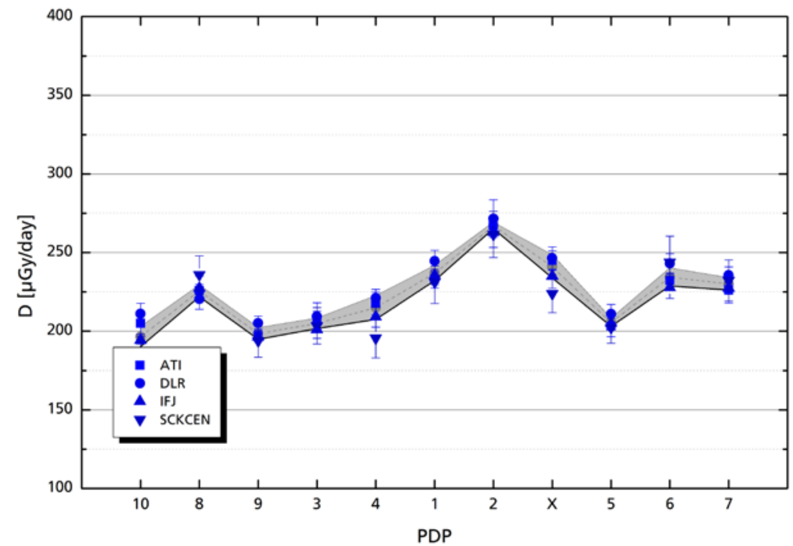
DOSIS 1

DOSIS 2



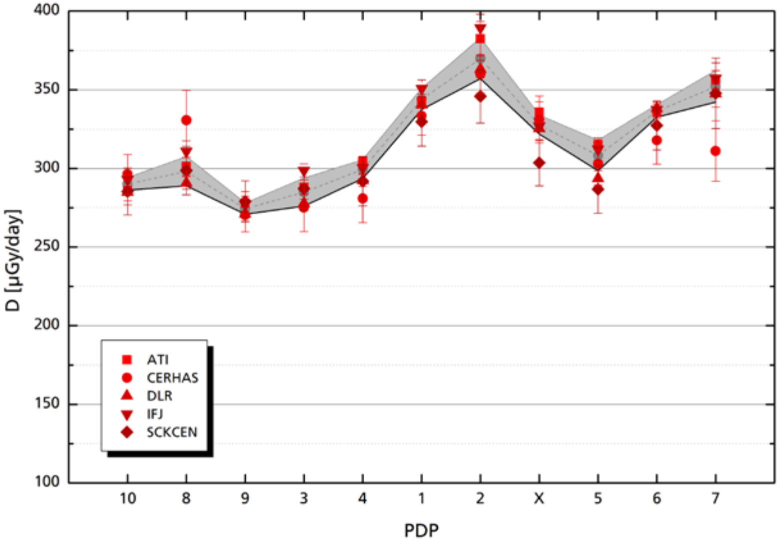


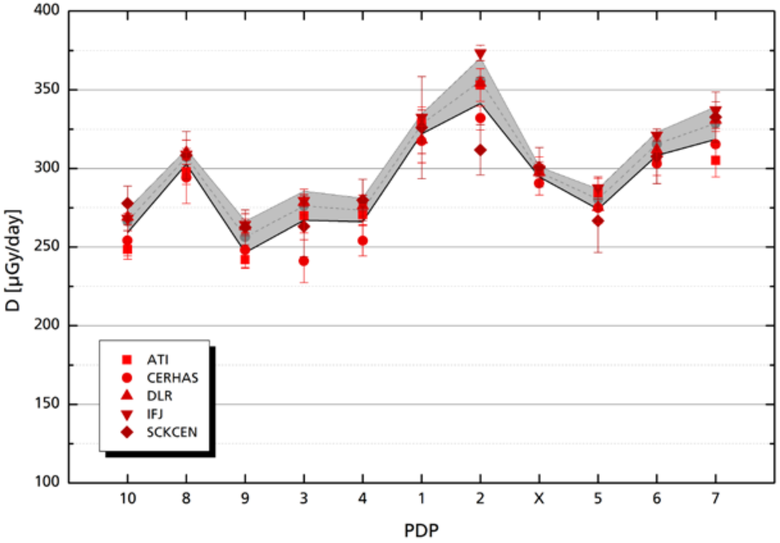


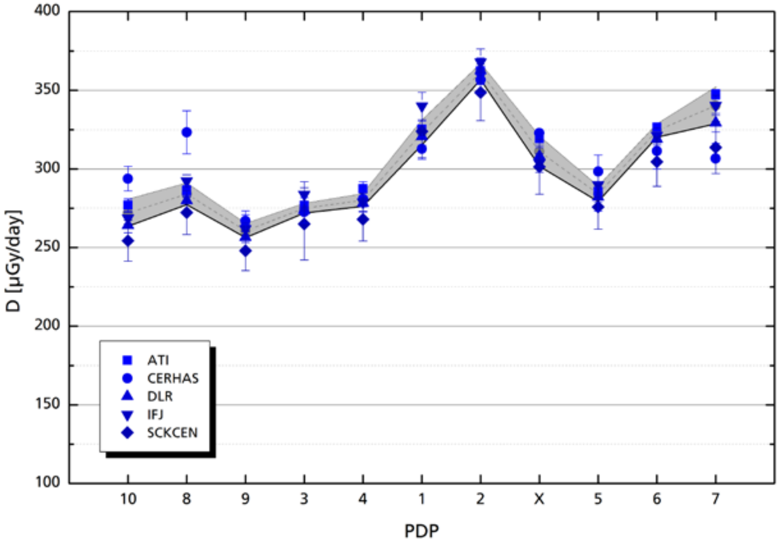


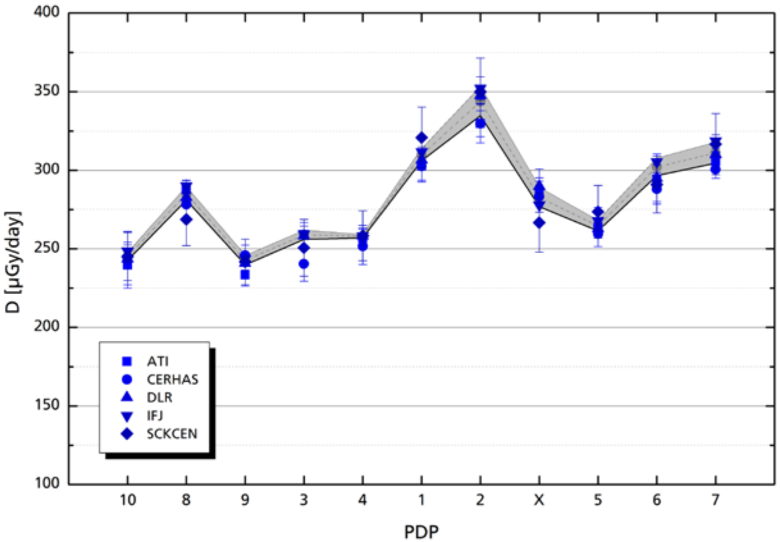
DOSIS 3D 1

DOSIS 3D 2









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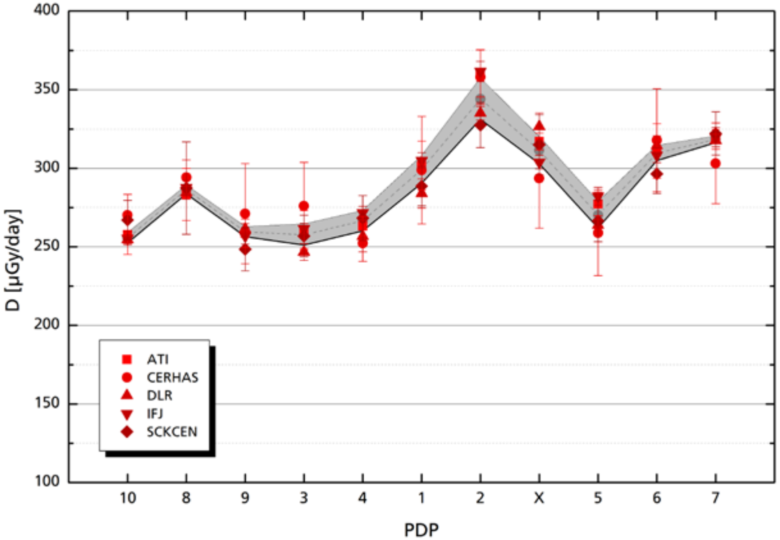
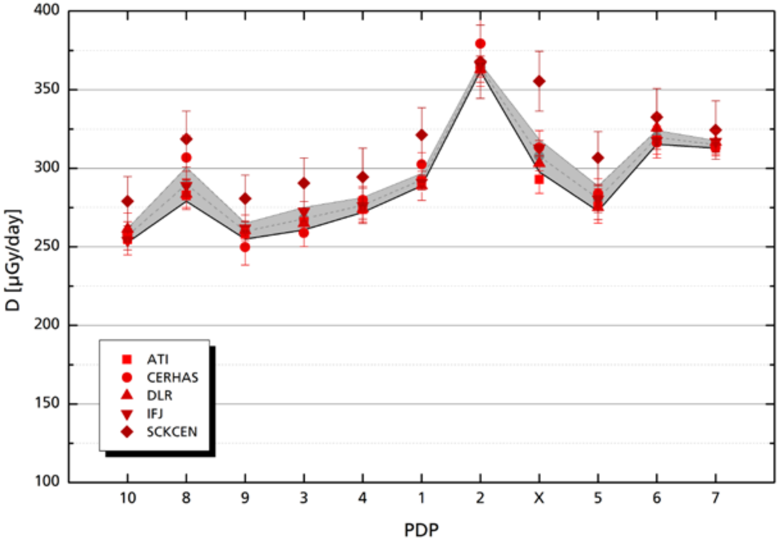
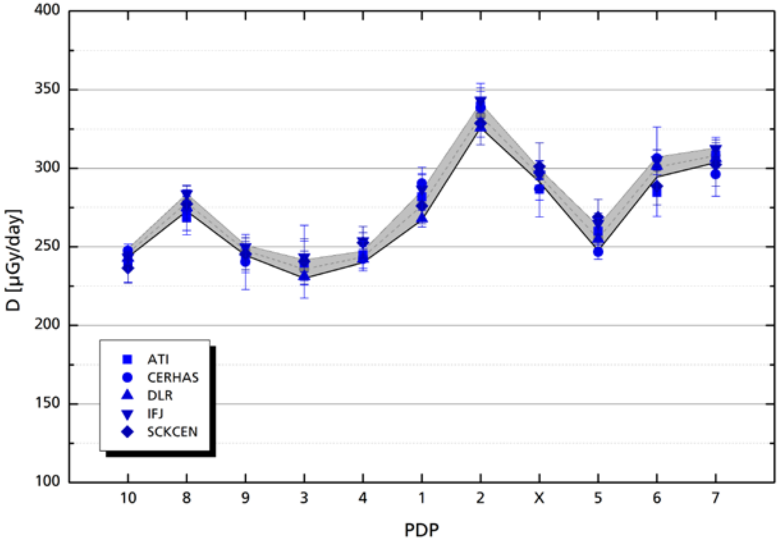
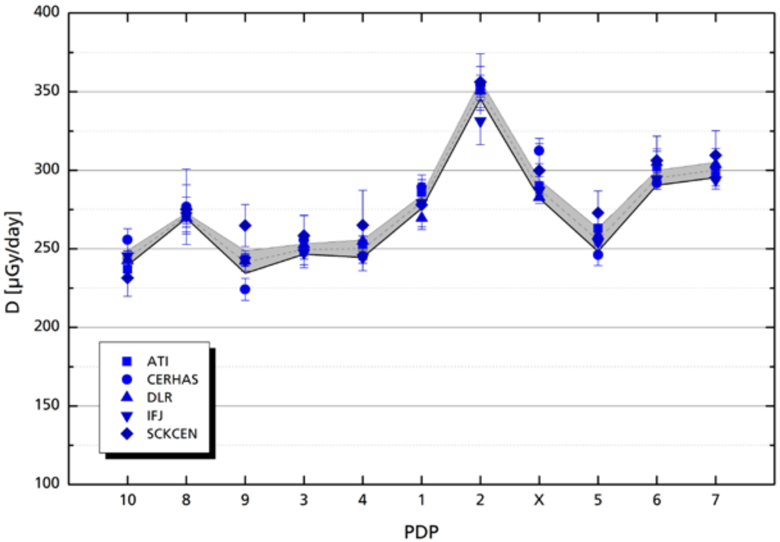
DOSIS 3D 3

DOSIS 3D 4









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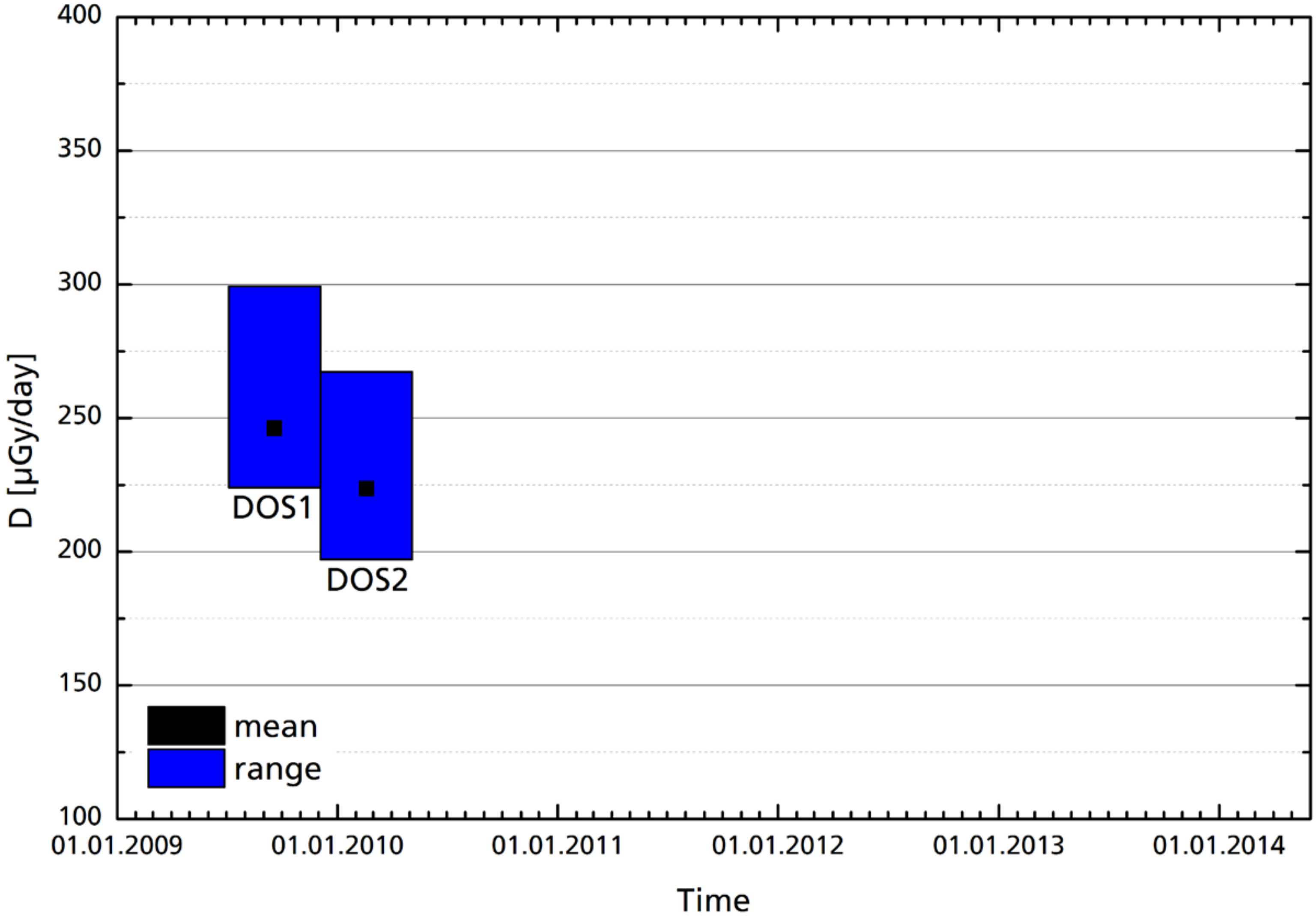
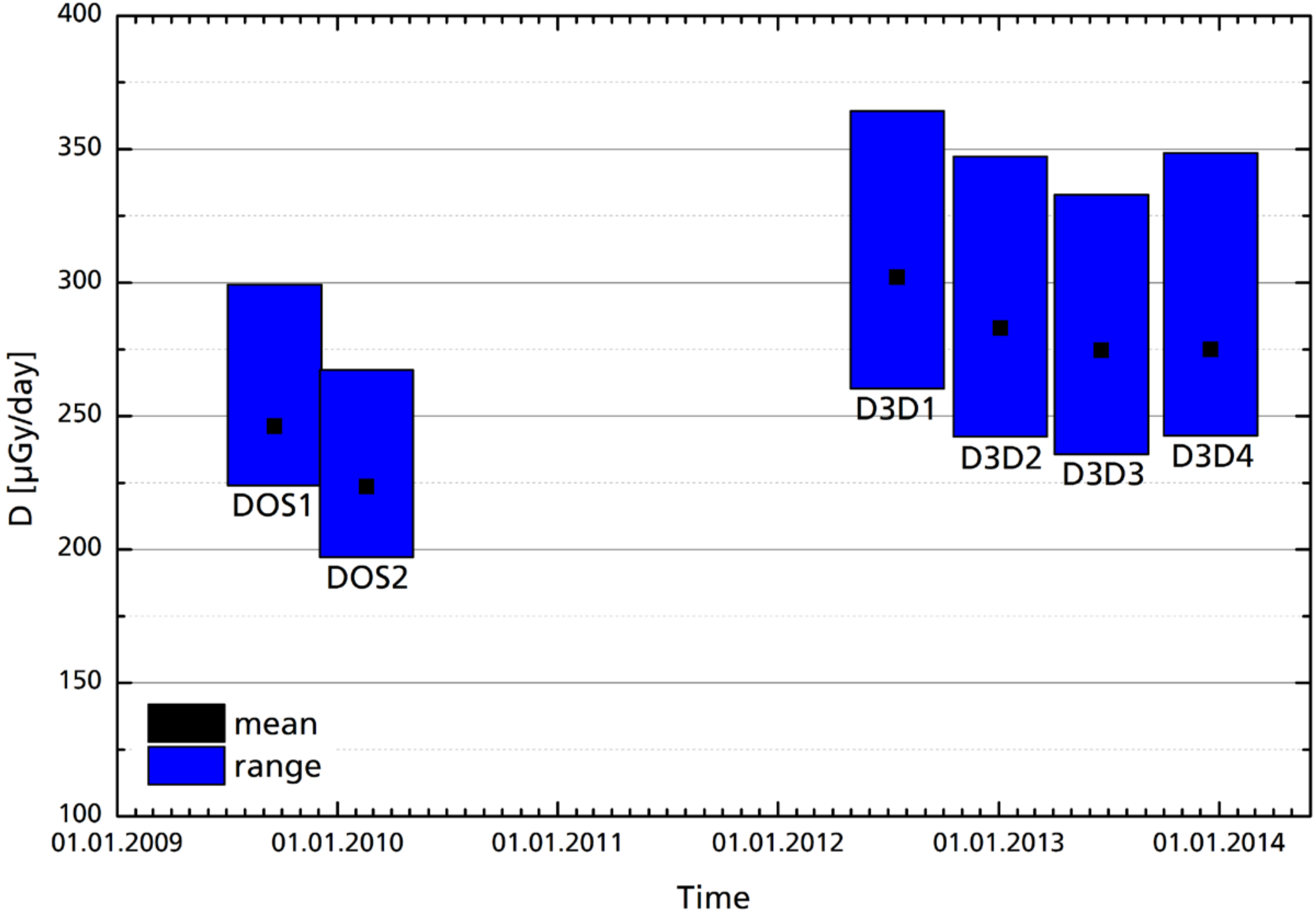
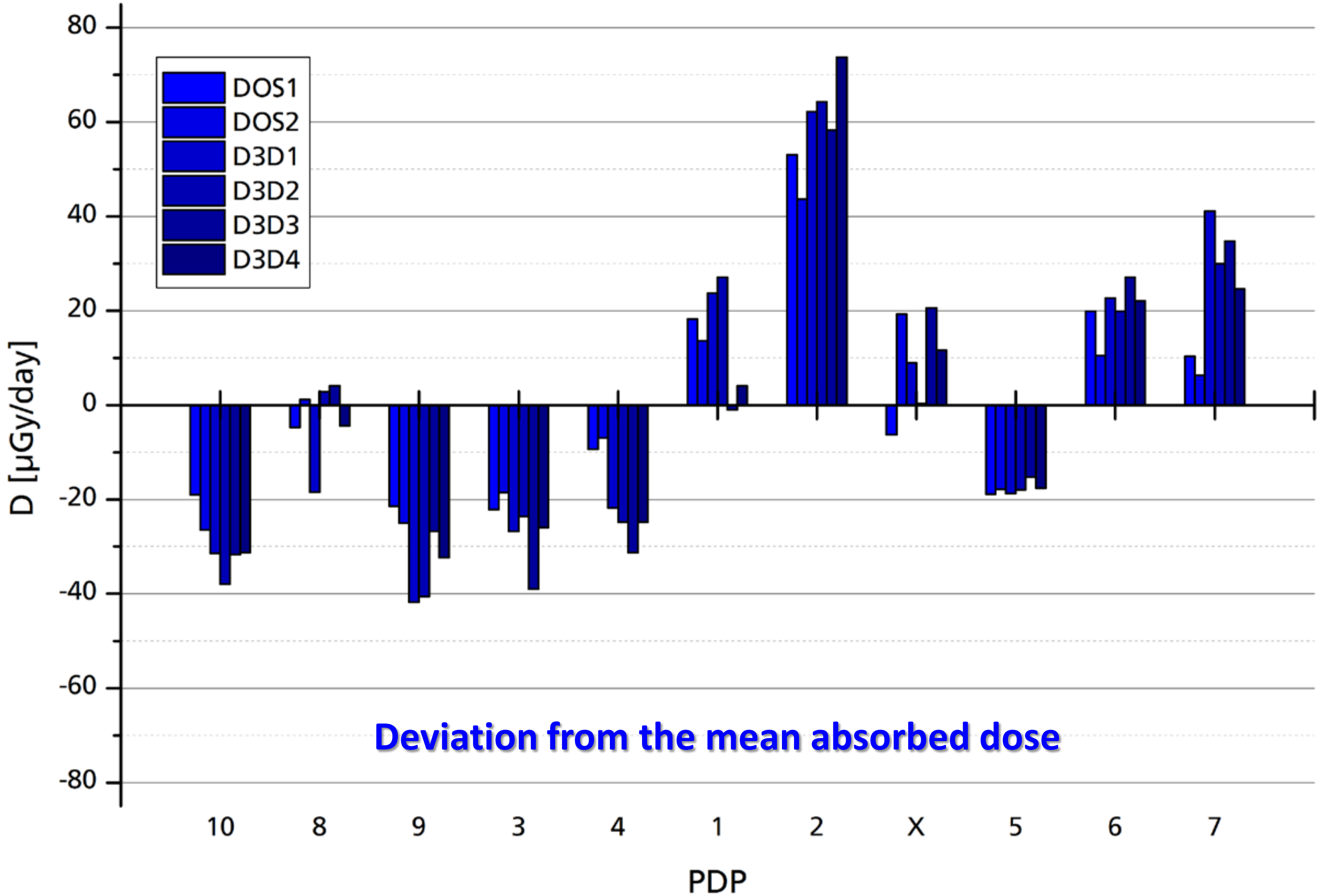
DOSIS & DOSIS 3D: PDP – Results 2



DOSIS & DOSIS 3D: PDP – Results 2



DOSIS & DOSIS 3D: PDP – Results 2



DOSIS & DOSIS 3D: Summary & Outlook

- DOSIS 3D 2: Very good agreement for the TLD data from all groups
  - differences can be explained due to the different LET dependency of the applied materials (TLD) and the different neutron sensitivity

- DOSIS: 200 ± 24 µGy/d to 267 ± 4 µGy/d (2009)
- DOSIS 3D: 237 ± 9 µGy/d to 340 ± 17 µGy/d (2013)
  - differences due to ISS Altitude change

- DOSIS 3D: Into depth comparison of data gathered with other passive (RAM, PADLES, PILLE) and active (DB-8, Tritel, Medipix) radiation detectors in progress

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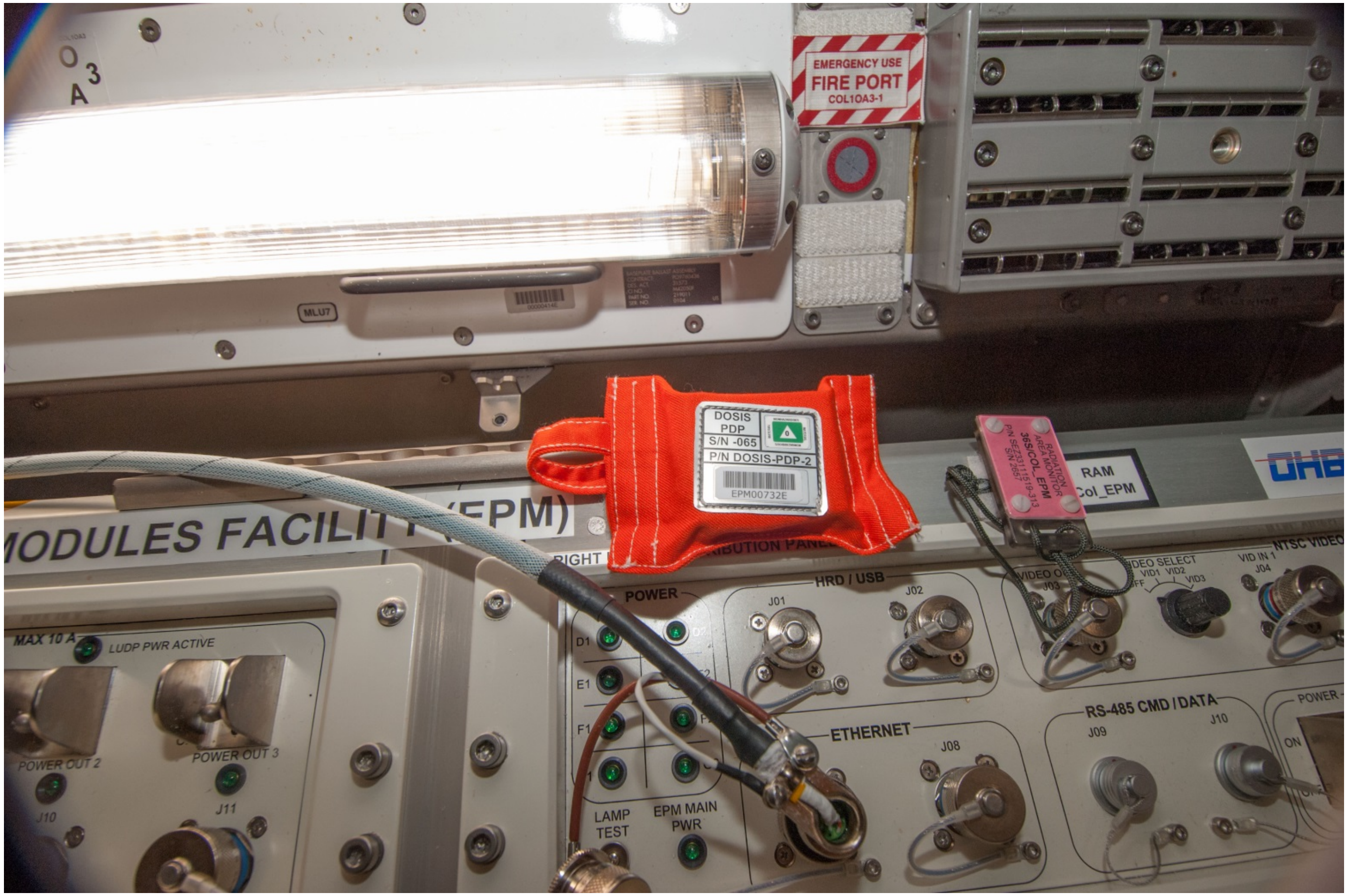
DOSIS & DOSIS 3D: Acknowledgements

We would like to thank all the astro- and cosmonauts working on the DOSIS & DOSIS 3D project:

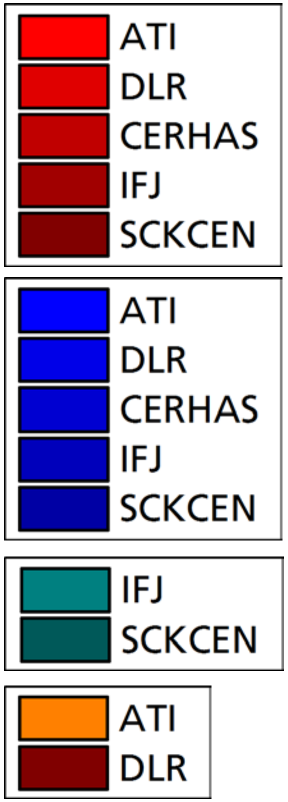
Frank de Winne, Tracy Caldwell-Dyson, Shannon Walker, Ron Garan, Mike Fossum, Andre Kuipers, Joe Acaba, Sunita Williams, Chris Hadfield, Chris Cassidy, Luca Parmitano, Michael Hopkins, Rick Mastracchio, Koichi Wakata, Alexander Gerst

DOSIS & DOSIS 3D: Backup



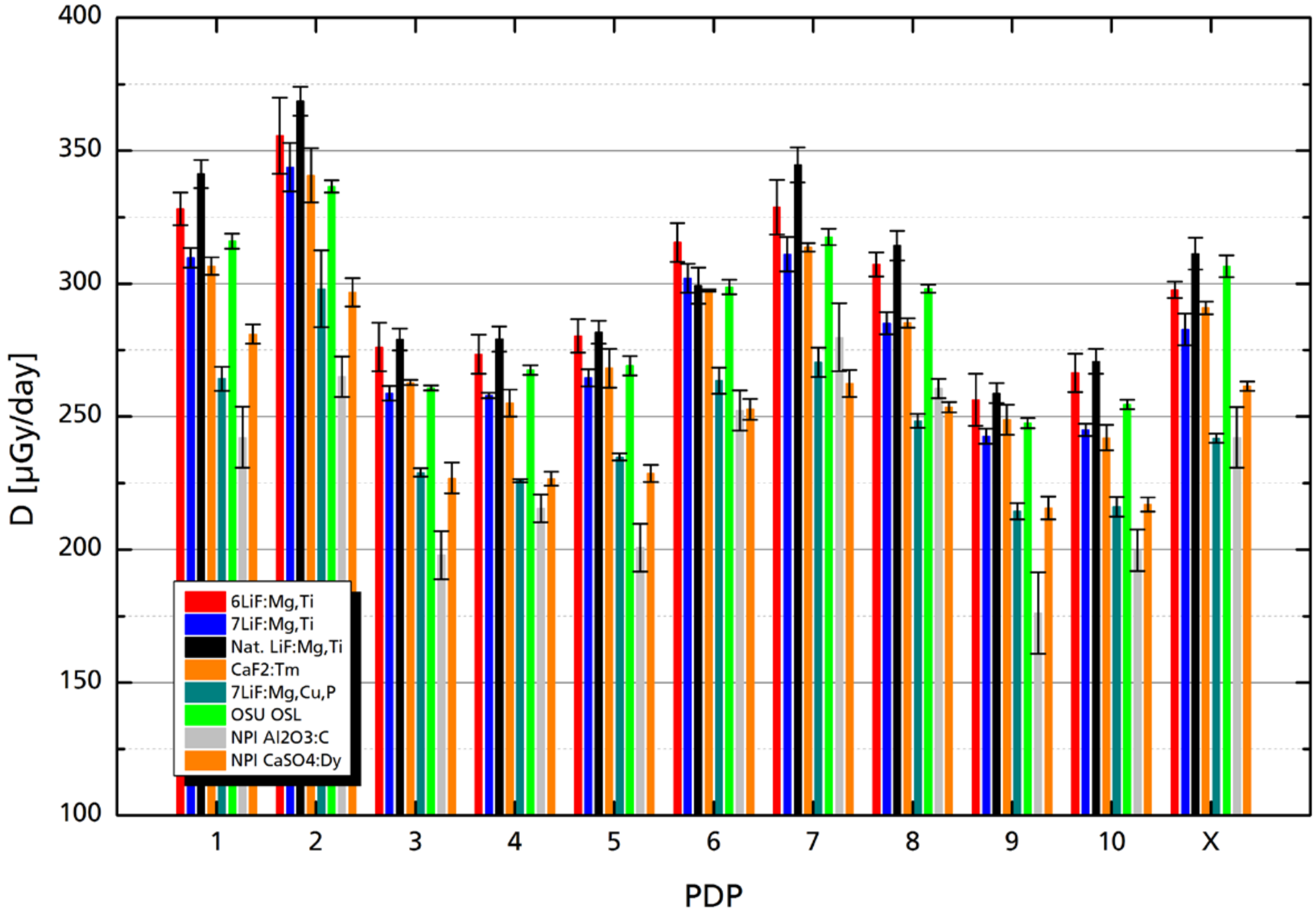
DOSIS 3D 2: Summary

Position	^{6}LiF:Mg,Ti	^{7}LiF:Mg,Ti	^{7}LiF:Mg,Cu,P	CaF_2:Tm
	Absorbed dose rate (µGy/d)			
BOX 1	325 ± 7	308 ± 9	269 ± 9	307 ± 5
BOX 2	345 ± 24	340 ± 14	293 ± 22	344 ± 7
BOX 3	266 ± 16	254 ± 8	219 ± 14	261 ± 4
BOX 4	272 ± 10	256 ± 3	224 ± 2	252 ± 10
BOX 5	278 ± 8	264 ± 7	233 ± 3	260 ± 17
BOX 6	310 ± 7	294 ± 7	258 ± 10	295 ± 4
BOX 7	324 ± 13	310 ± 8	263 ± 13	317 ± 2
BOX 8	304 ± 7	282 ± 9	246 ± 5	284 ± 1
BOX 9	256 ± 10	240 ± 7	212 ± 6	241 ± 14
BOX 10	264 ± 12	243 ± 6	212 ± 7	241 ± 8
BOX X	298 ± 4	281 ± 9	237 ± 7	294 ± 1



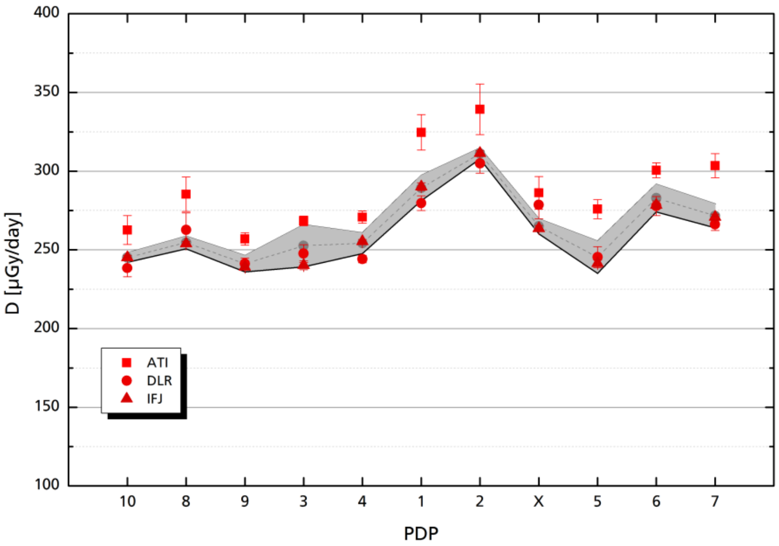
TLD data based on the average from SCK-CEN, ATI, IFJ, CER-HAS and DLR for the respective TLD materials.

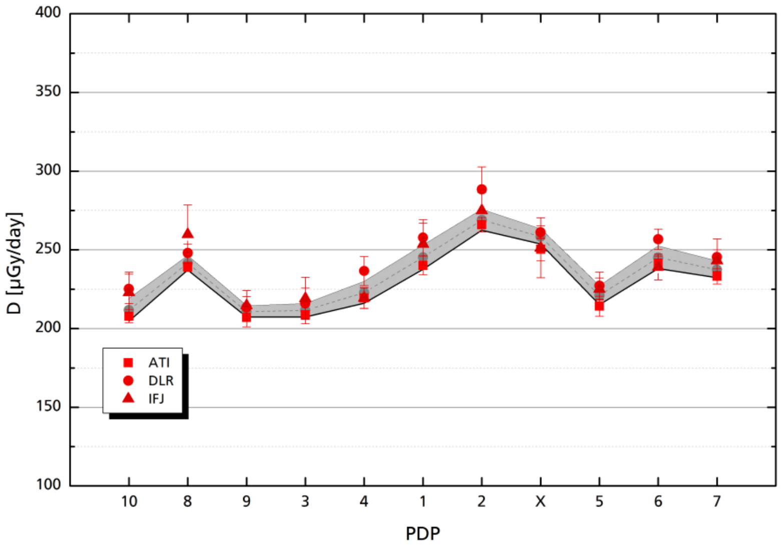
DOSIS 3D 2: Summary

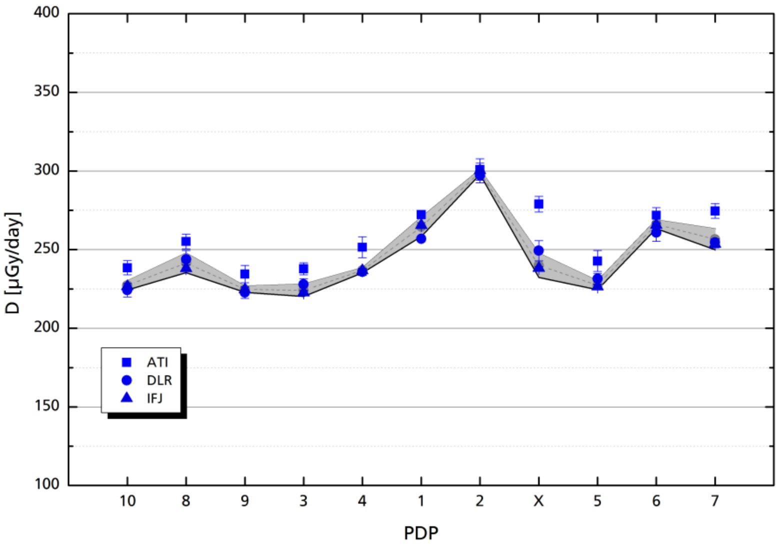


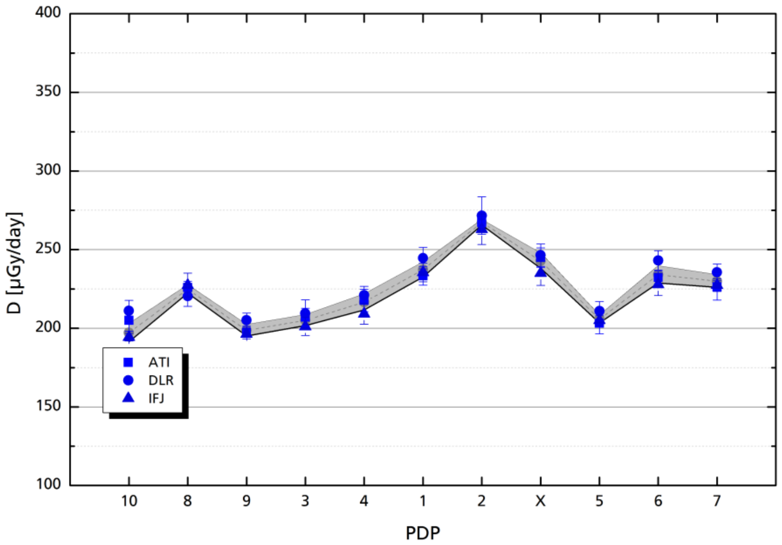
DOSIS 1

DOSIS 2

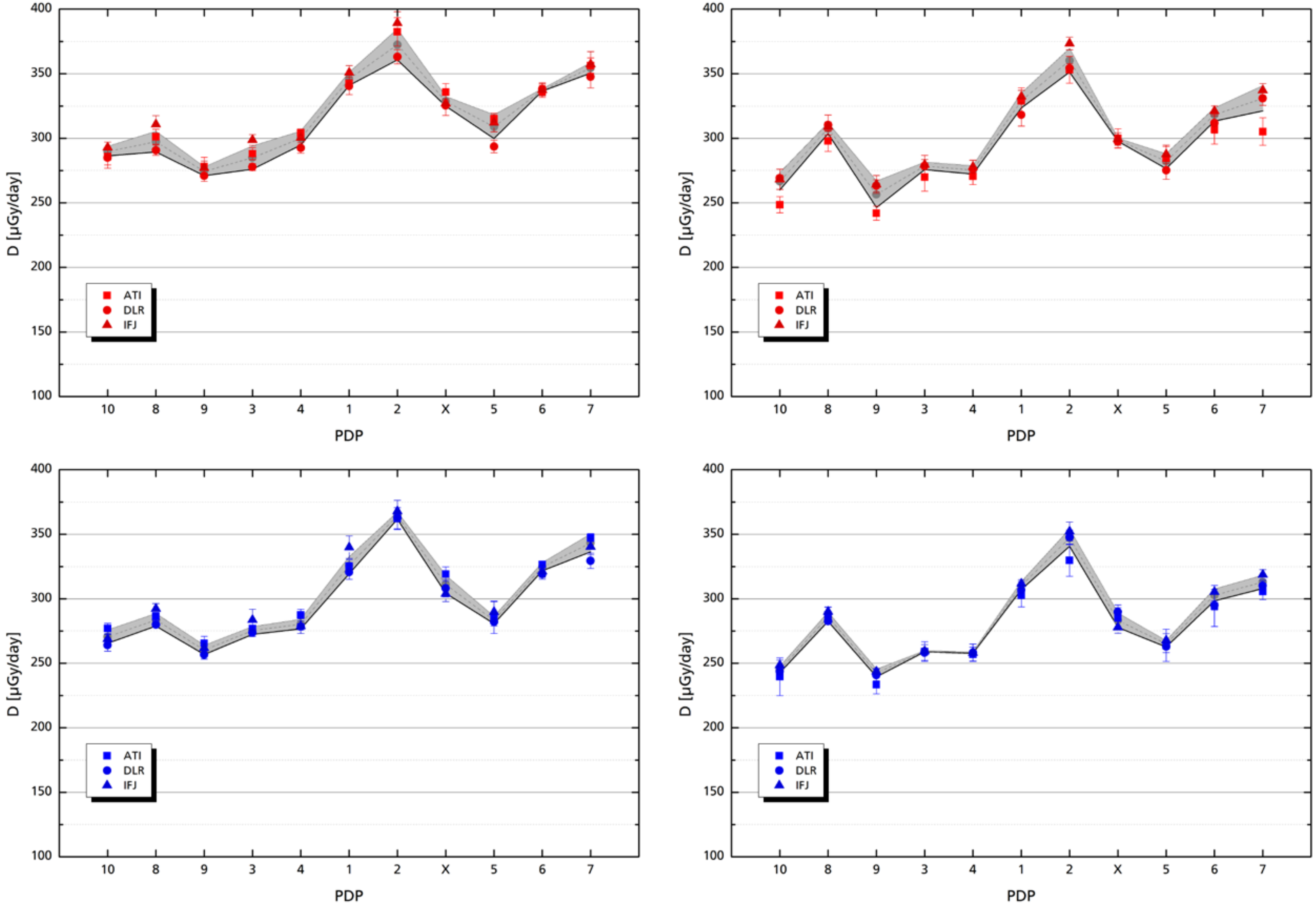




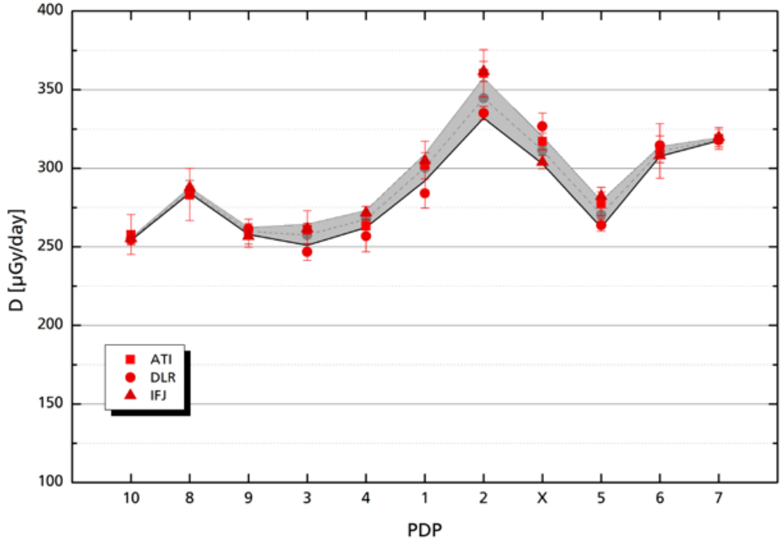


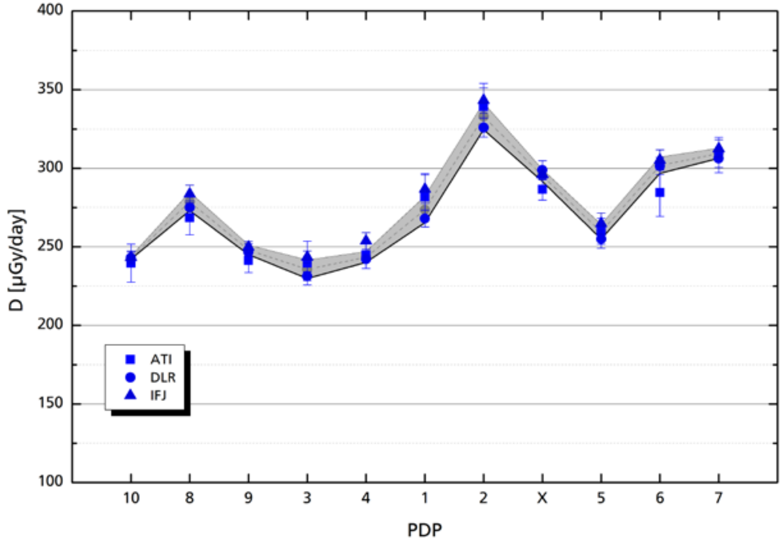


DOSIS 3D 1 | DOSIS 3D 2

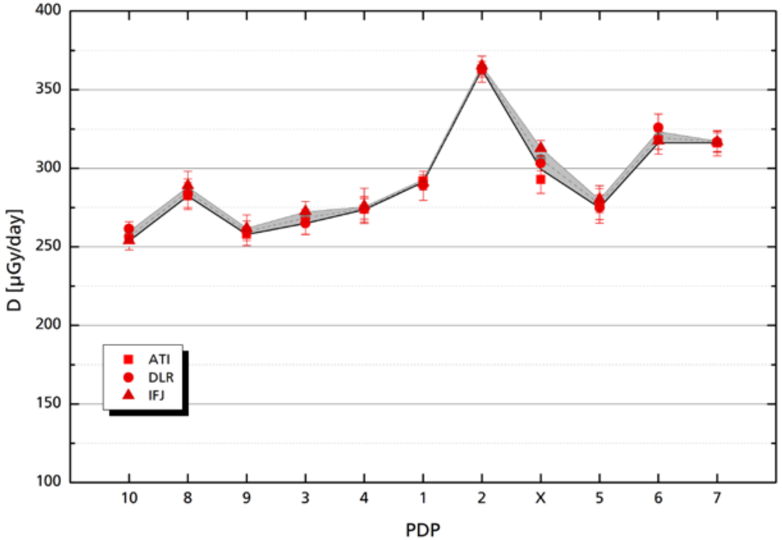


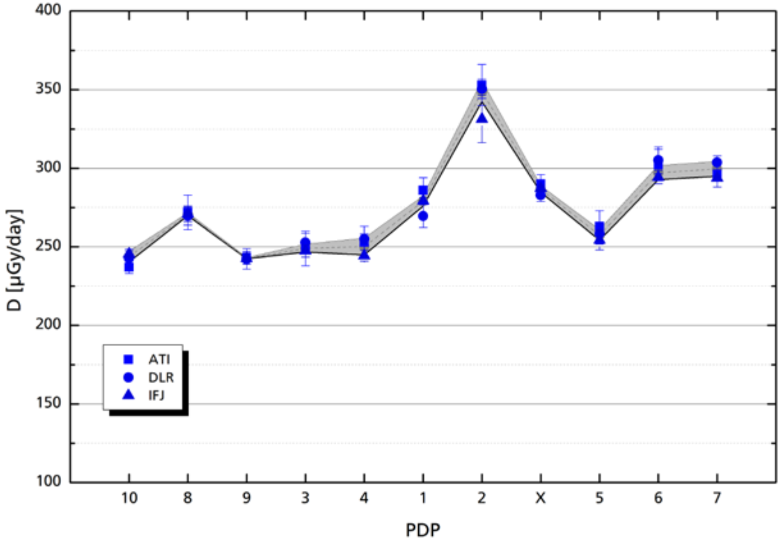
DOSIS 3D 3



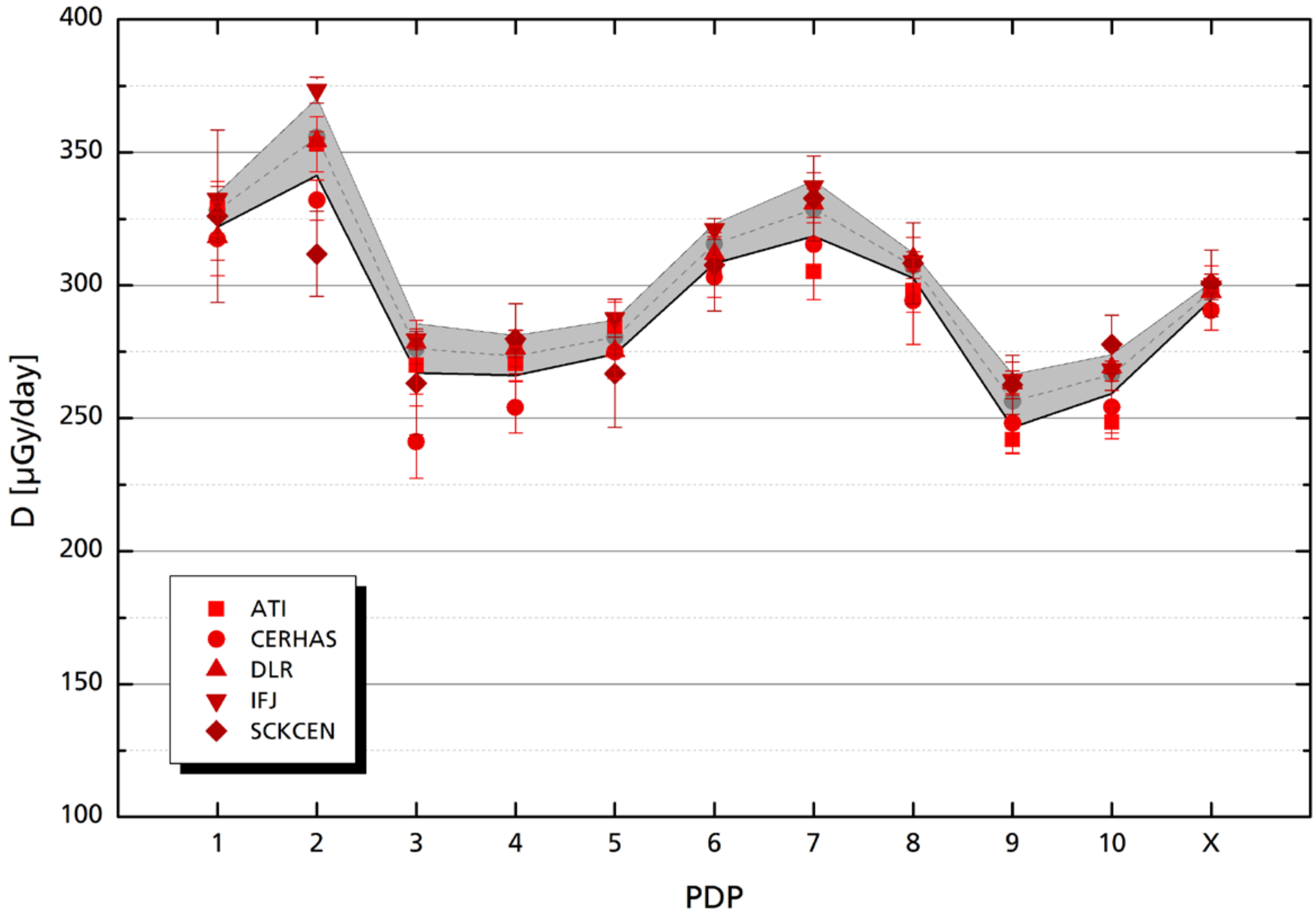


DOSIS 3D 4

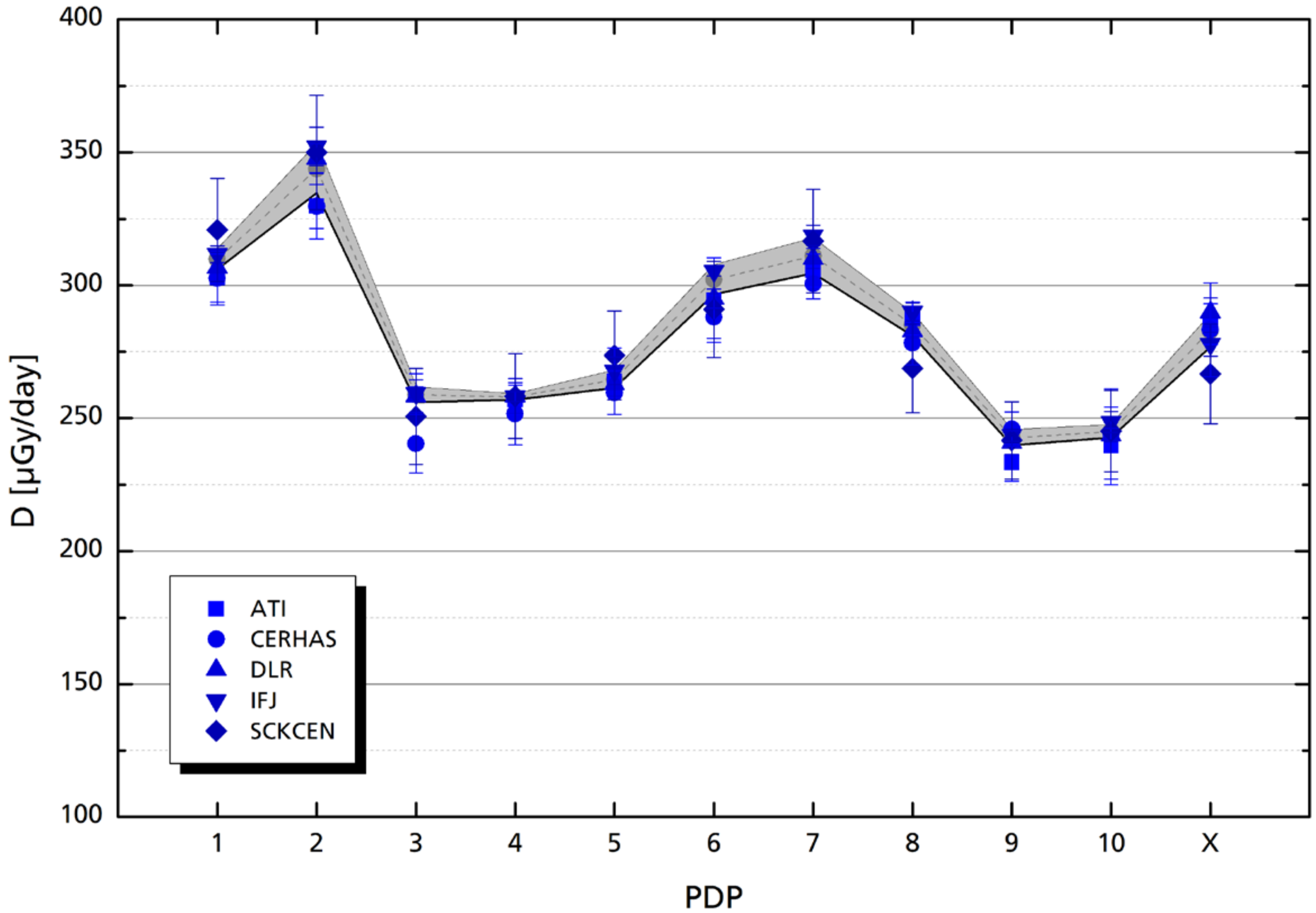




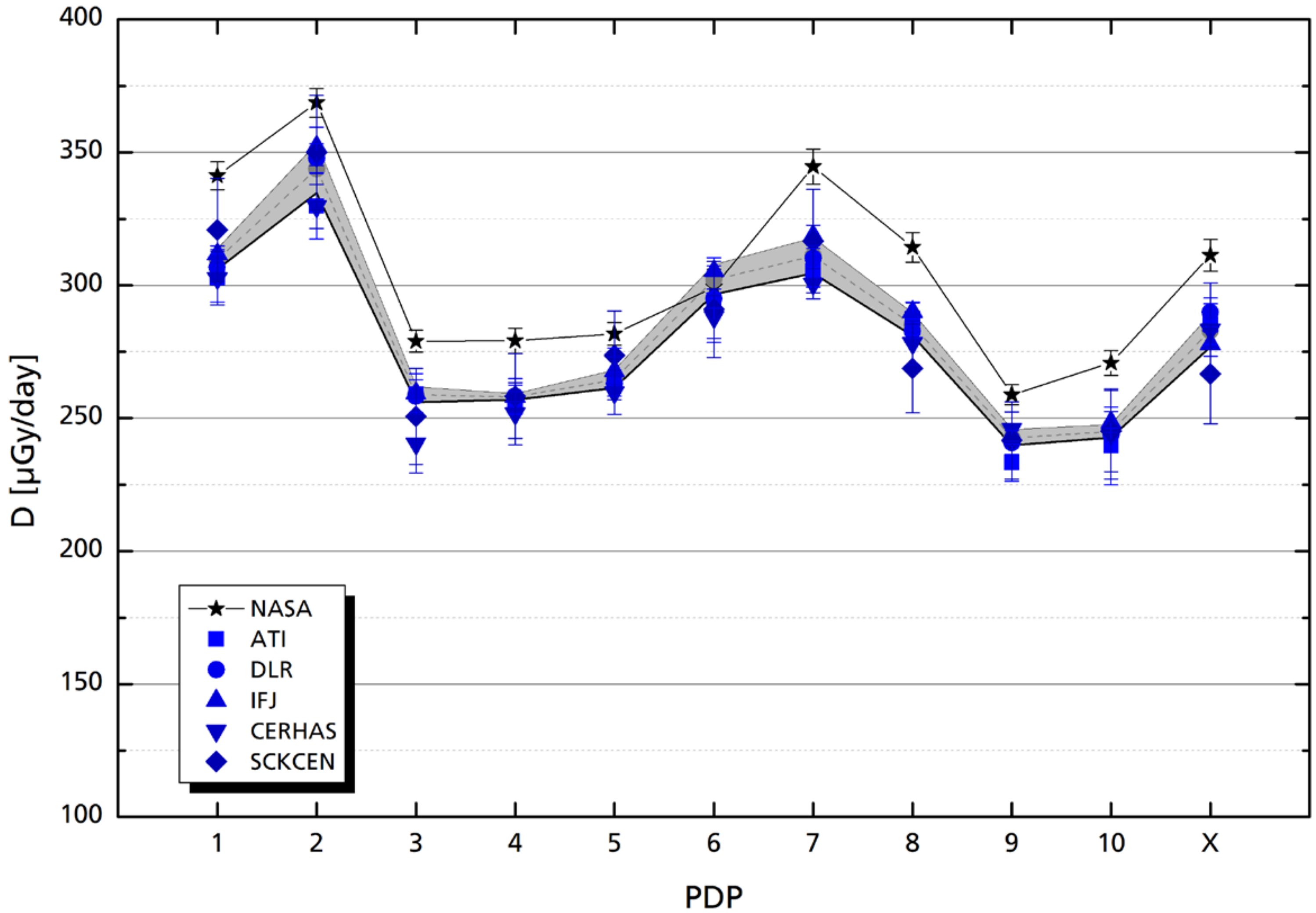
DOSIS 3D 2 – 6LiF:Mg,Ti daily dose [uGy/d]



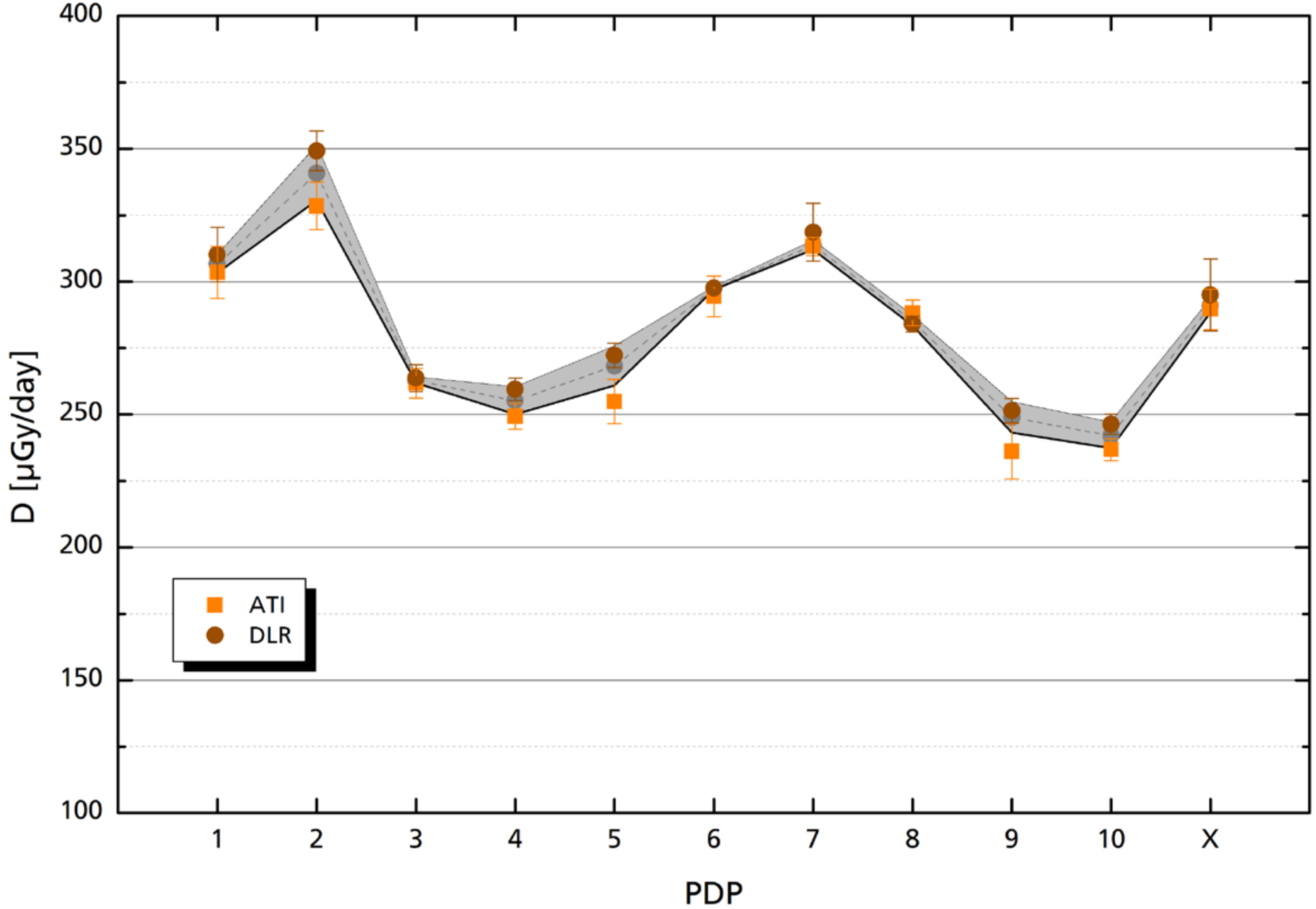
DOSIS 3D 2 – 7LiF:Mg,Ti daily dose [uGy/d]



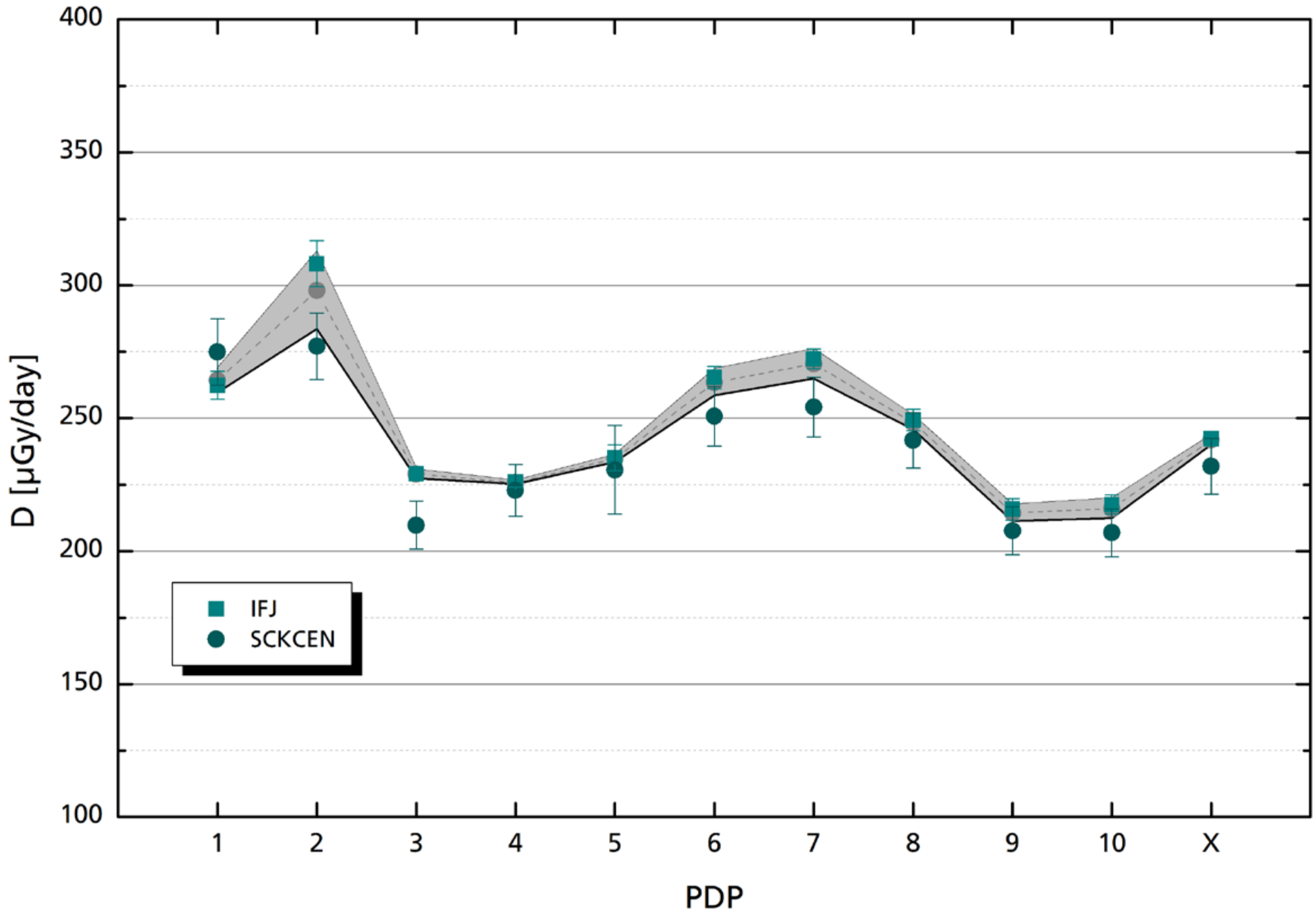
DOSIS 3D 2 – 7LiF:Mg,Ti + Nat. LiF:Mg,Ti daily dose [uGy/d]



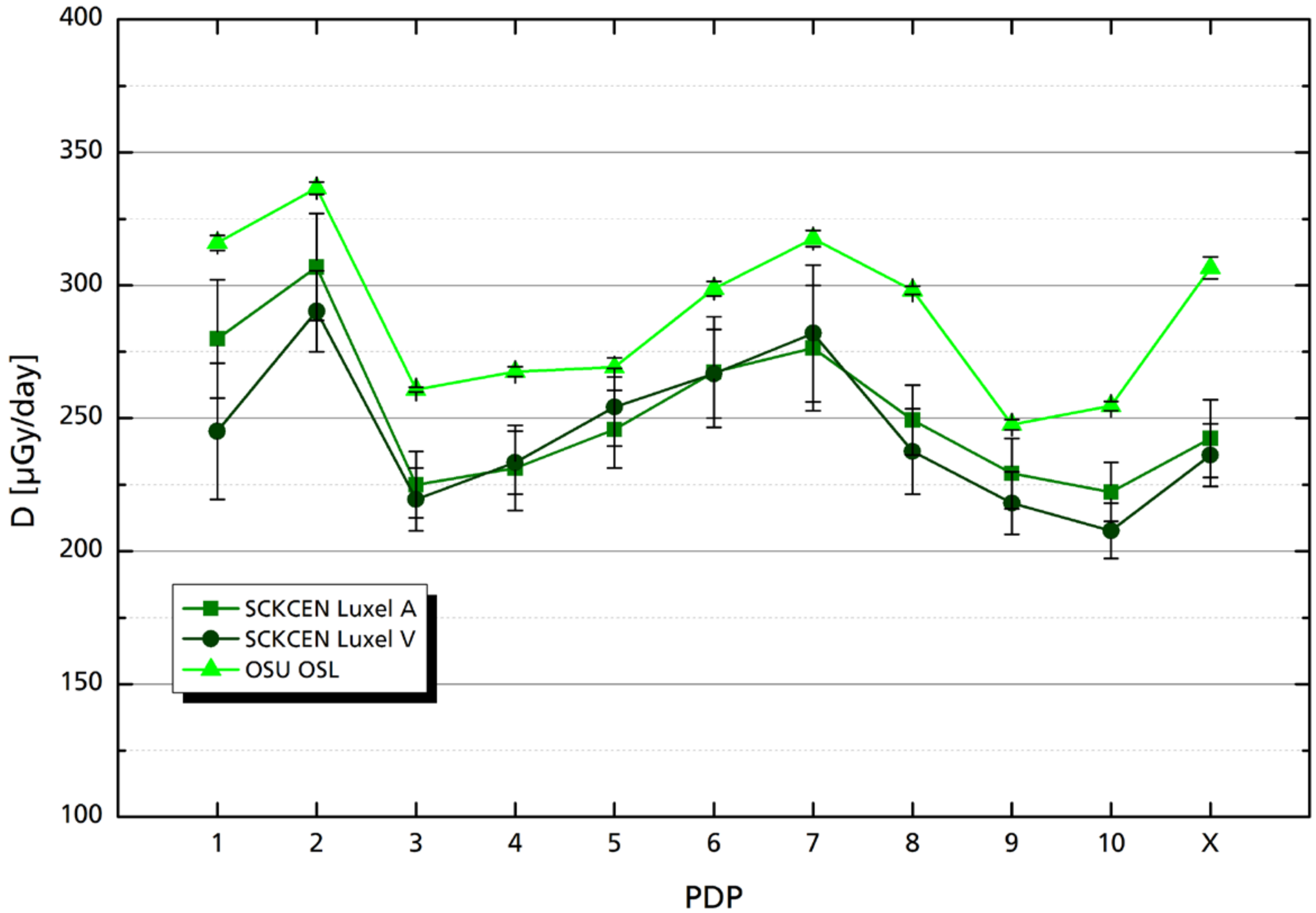
DOSIS 3D 2 – CaF2:Tm daily dose [uGy/d]



DOSIS 3D 2 – 7LiF:Mg,Cu,P daily dose [uGy/d]



DOSIS 3D 2 – OSL daily dose [uGy/d]



DOSIS 3D 2 – NPI daily dose [uGy/d]