TL Dosimetry in Columbus during DOSIS-II

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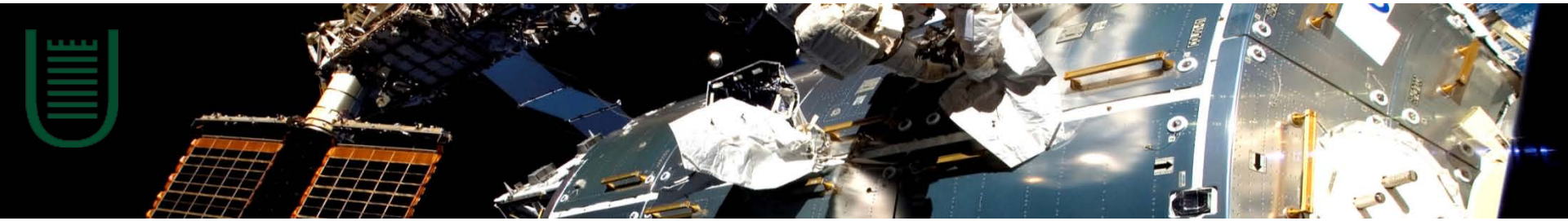
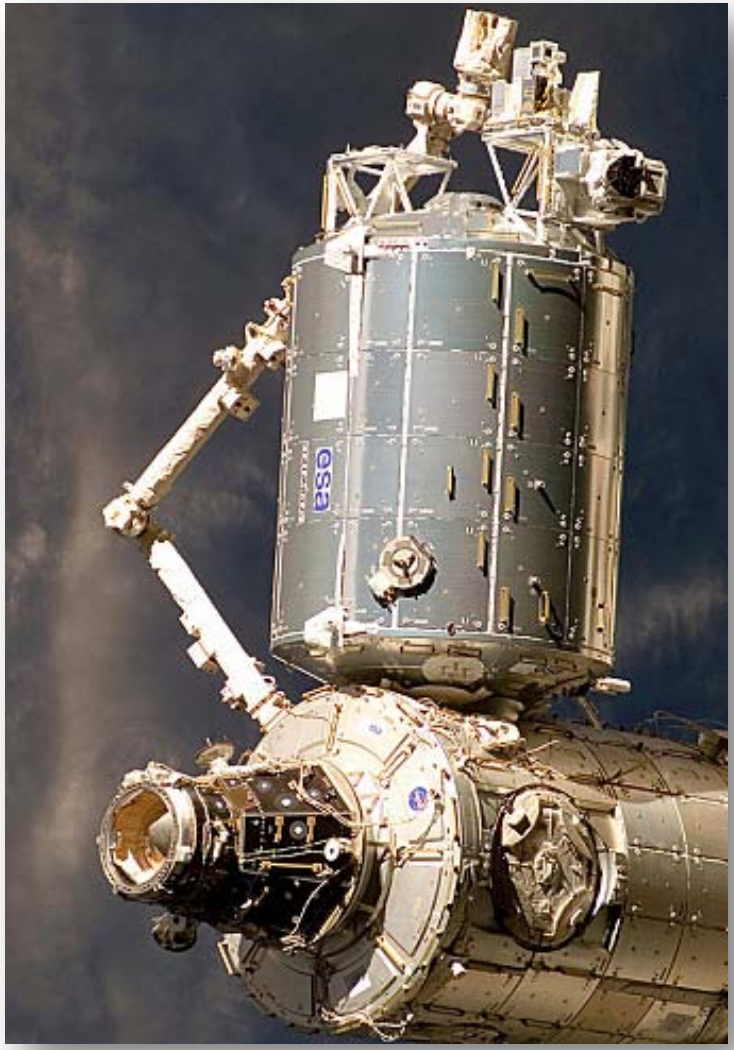


Outline

- Introduction
  - Experiment overview
  - Timetable of DOSIS-II
  - TL phosphors and experimental protocol
- Evaluation of DOSIS-II
  - Correction for background exposure
  - Evaluation of DOSIS-II (TLD-300/TLD-600/TLD-700)
- Comparison of DOSIS-I and DOSIS-II
  - Comparison of preliminary results
    - → ATI vs DLR
    - → DOSIS-I vs DOSIS-II



Experiment overview

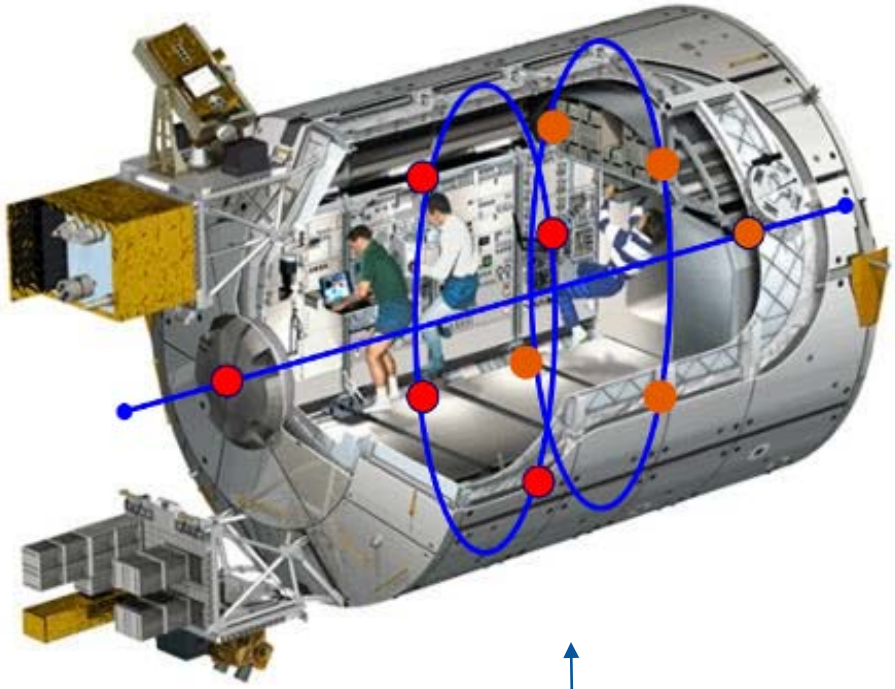
- DOSIS (Dose Distribution Inside the ISS) – a multi lateral project under direction of DLR (German Aerospace Centre)

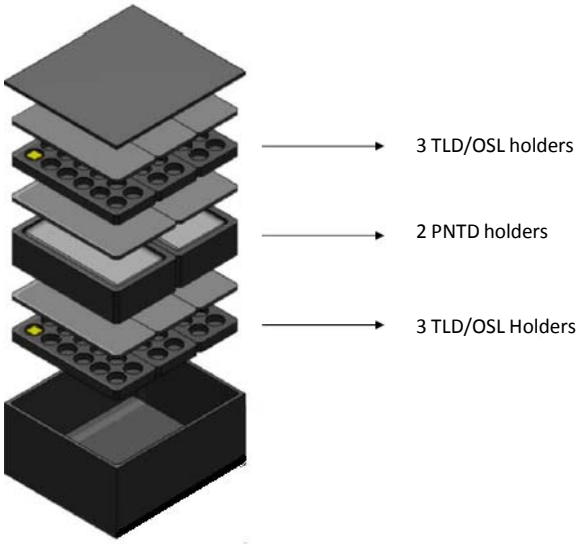
- Characterization of radiation field and dose mapping onboard Columbus
  - Absorbed dose
  - Particle flux density
  - Energy spectra

- Current status of DOSIS-I and DOSIS-II
  - Phase I already reported (Berger *et al.*)
  - Preliminary results of phase II (ATI, DLR)

DOSIS-II experiment

- Radiation dose mapping onboard the European Columbus laboratory
- Passive Dosimeter Packages (PDP) comprising thermoluminescence and nuclear track detectors





Timetable of DOSIS-II

① 06/08/2009: Annealing (ATI)

→ 102 days

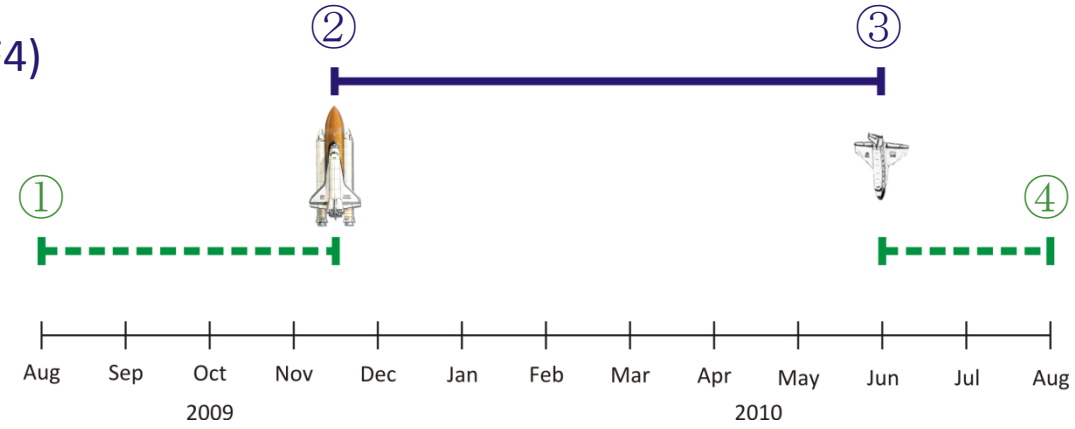
② 16/11/2009: Launch (STS-129/ULF3)

→ 191 days

③ 26/05/2010: Return (STS-132/ULF4)

→ 72 days

④ 05/08/2010: Readout (ATI)



TL phosphors and experimental protocol

	TL phosphor	Reader	Heating rate	Pre-heat	Cooling rate	Annealing cycle	Calibration method	Calibration source
ATI	TLD-300 (CaF_2:Tm)	TL-DAT.II (Thorn EMI 9635 QB)	5°C/s	no	slow	400°C (1 h)	single-chip	^{60}Co γ-rays
	TLD-600 (LiF:Mg,Ti)*							
	TLD-700 (LiF:Mg,Ti)**							
DLR	TLD-300 (CaF_2:Tm)	Harshaw 5500 (Hamamatsu RC095 HA)	5°C/s	no	slow	400°C (1h) 100°C (2h)	single-chip	^{137}Cs γ-rays
	TLD-600 (LiF:Mg,Ti)*							
	TLD-700 (LiF:Mg,Ti)**							

* TLD-600: enriched in ^{6}Li

** TLD-700: enriched in ^{7}Li

Background correction

Dose accumulated during storage on ground $D_{BG} = \frac{D_{tot}}{t_{tot}} (t_L + t_R) \longrightarrow D_{corr} = D_{tot} - D_{BG}$

	From	To	Duration [days]
t_L	Annealing	Launch	102
t_R	Return	Readout	72
t_{L-R}	Launch	Return	191
t_{tot}	Annealing	Readout	365

Annealing	06/08/2009
Launch	16/11/2009
Return	26/05/2010
Readout	05/08/2010

	D_{tot} [mGy]	σ [mGy]	σ [%]	D_{BG} [mGy]	σ [mGy]	σ [%]
TLD-300	**0.71**	0.03	3.7	**0.37**	0.01	3.7
TLD-600	**0.63**	0.02	3.4	**0.33**	0.01	3.4
TLD-700	**0.63**	0.02	2.7	**0.33**	0.01	2.7

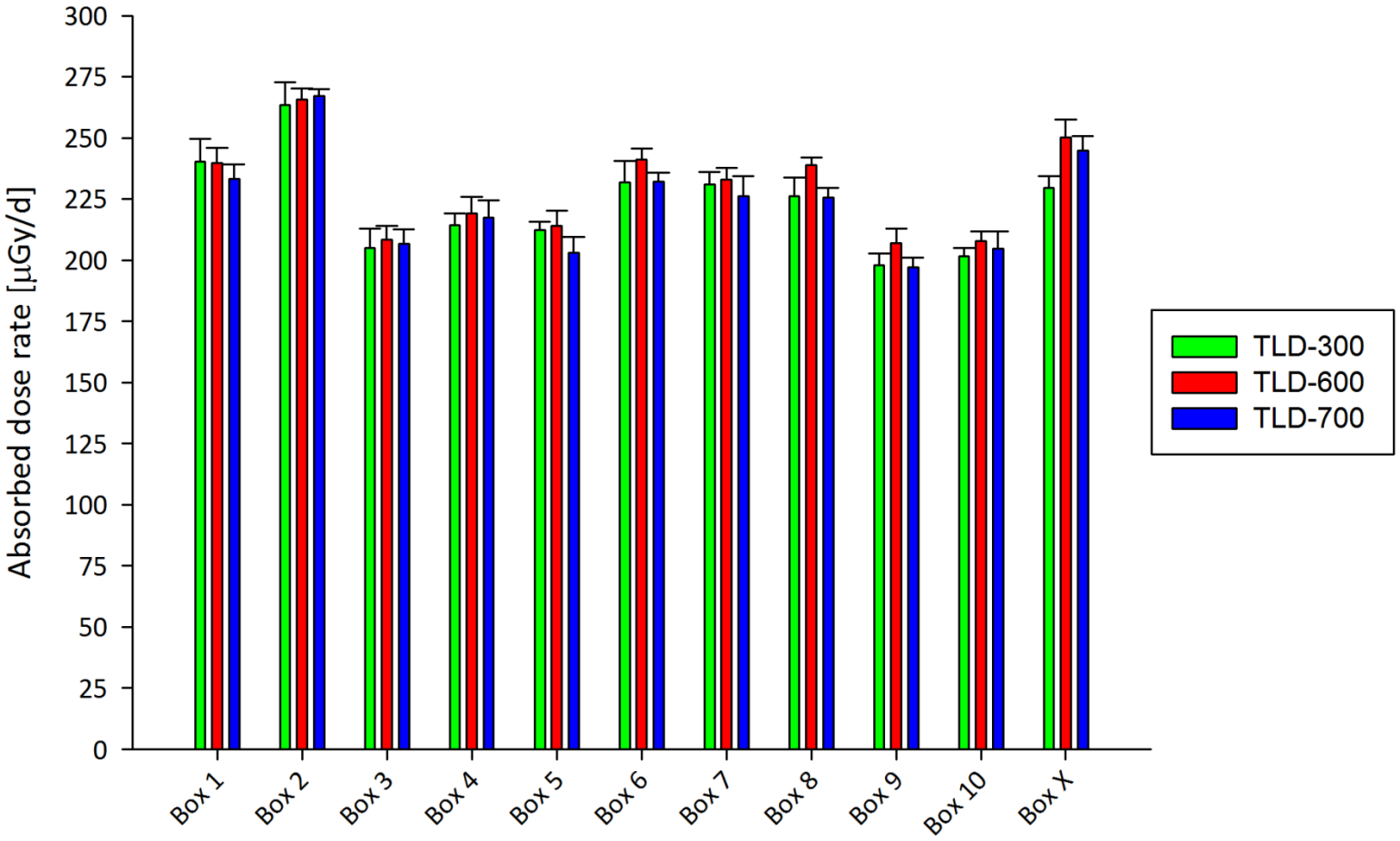
DOSIS-II: Absorbed dose

	TLD-300		TLD-600		TLD-700	
PDP	D_{corr} [mGy]	σ [mGy]	D_{corr} [mGy]	σ [mGy]	D_{corr} [mGy]	σ [mGy]
Box 1	**45.87**	1.82	**45.80**	1.15	**44.52**	1.14
Box 2	**50.29**	1.78	**50.73**	0.88	**51.01**	0.56
Box 3	**39.13**	1.56	**39.81**	1.07	**39.49**	1.09
Box 4	**40.92**	0.95	**41.86**	1.27	**41.53**	1.35
Box 5	**40.55**	0.67	**40.86**	1.21	**38.75**	1.26
Box 6	**44.28**	1.65	**46.06**	0.87	**44.31**	0.75
Box 7	**44.12**	0.99	**44.48**	0.93	**43.17**	1.61
Box 8	**43.21**	1.45	**45.64**	0.58	**43.08**	0.77
Box 9	**37.82**	0.88	**39.50**	1.16	**37.64**	0.78
Box 10	**38.49**	0.64	**39.66**	0.80	**39.12**	1.32
Box X	**43.83**	0.91	**47.76**	1.40	**46.73**	1.17

DOSIS-II: Absorbed dose rate

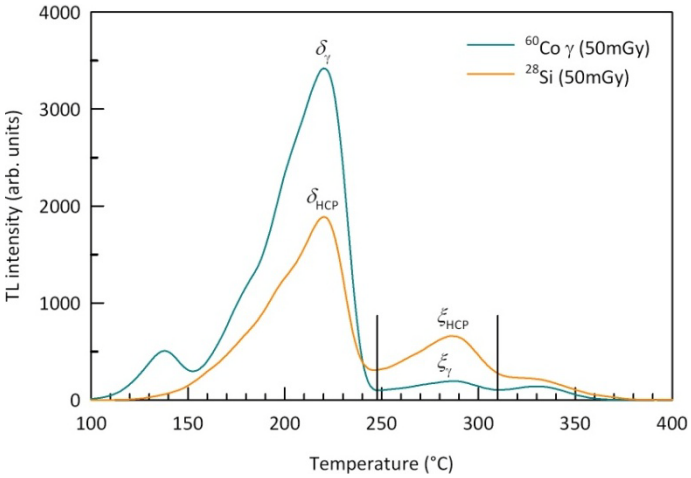
	TLD-300		TLD-600		TLD-700	
PDP	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]
Box 1	**240.1**	9.5	**239.8**	6.0	**233.1**	6.0
Box 2	**263.3**	9.3	**265.6**	4.6	**267.1**	2.9
Box 3	**204.9**	8.2	**208.4**	5.6	**206.8**	5.7
Box 4	**214.2**	5.0	**219.2**	6.6	**217.4**	7.1
Box 5	**212.3**	3.5	**214.0**	6.4	**202.9**	6. 6
Box 6	**231.8**	8.7	**241.1**	4.6	**232.0**	3.9
Box 7	**231.0**	5.2	**232.9**	4.9	**226.0**	8.4
Box 8	**226.2**	7.6	**238.9**	3.0	**225.5**	4.0
Box 9	**198.0**	4.6	**206.8**	6.1	**197.1**	4.1
Box 10	**201.5**	3.4	**207.7**	4.2	**204.8**	6.9
Box X	**229.5**	4.8	**250.1**	7.4	**244.7**	6.1

DOSIS-II: Absorbed dose rate

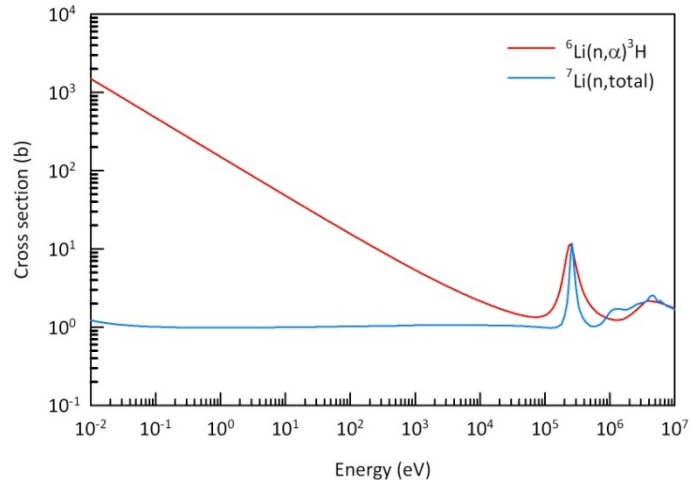


Indicators for (slow) neutrons

- HIGH-TEMPERATURE RATIO (HTR) IN TLD-600
  - $^6Li(n,\alpha)^3H$ → indication for (slow) neutrons
  - $$HTR = \frac{\frac{\xi_{HCP}}{\delta_{HCP}}}{\frac{\xi_\gamma}{\delta_\gamma}} = \frac{\xi_{HCP}\,\delta_\gamma}{\delta_{HCP}\,\xi_\gamma}$$



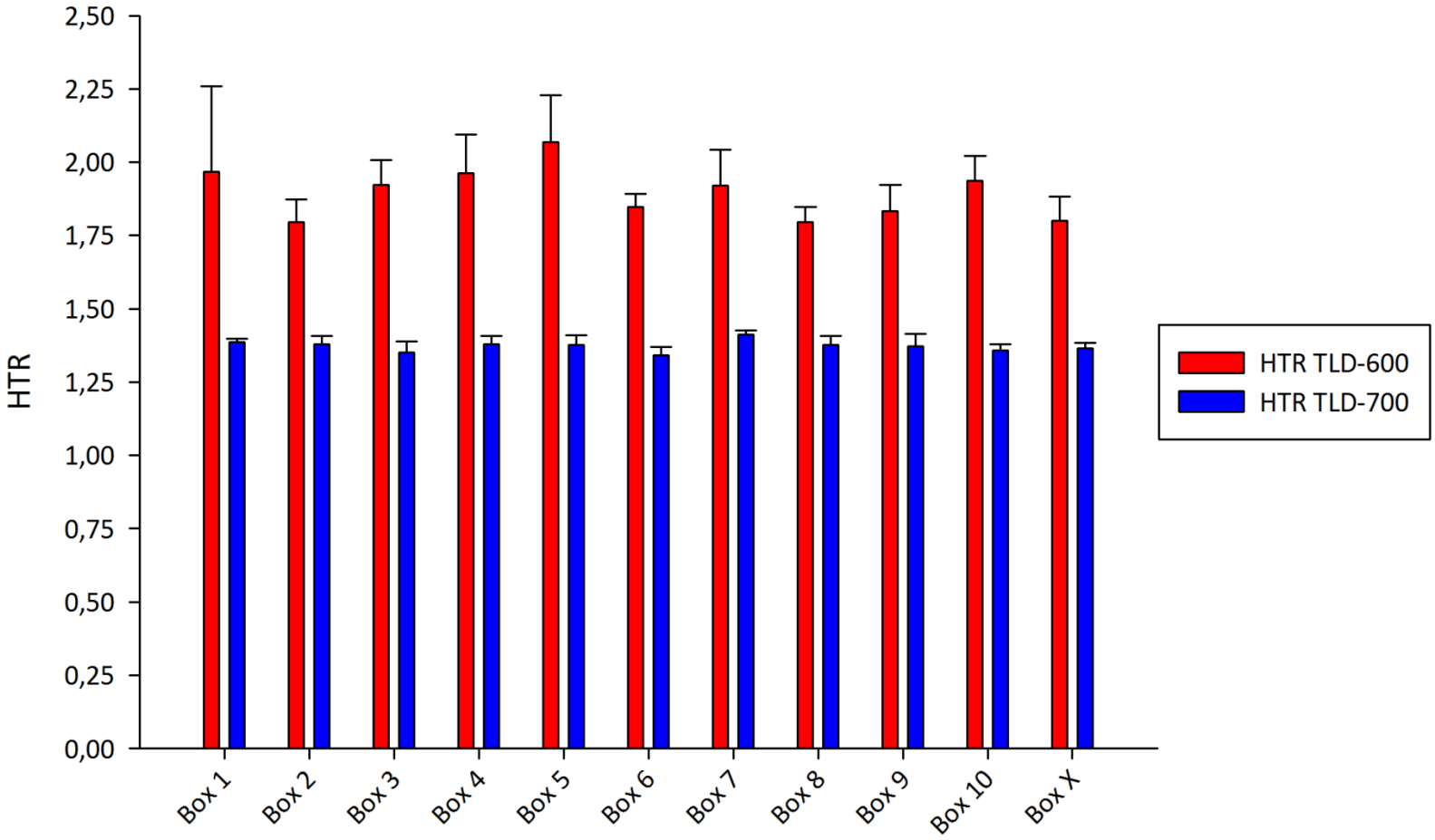
- PAIR METHOD USING TLD-600 AND TLD-700
  - Different neutron cross sections of ^6Li and ^7Li
  - $D_n[^{60}\mathrm{Co}-\mathrm{equiv.\,Gy}] = D_{600} - D_{700}$
  - Significantly lower efficiency than HTR
    [ref. Hajek *et al.*, WRMISS-13, Krakow]



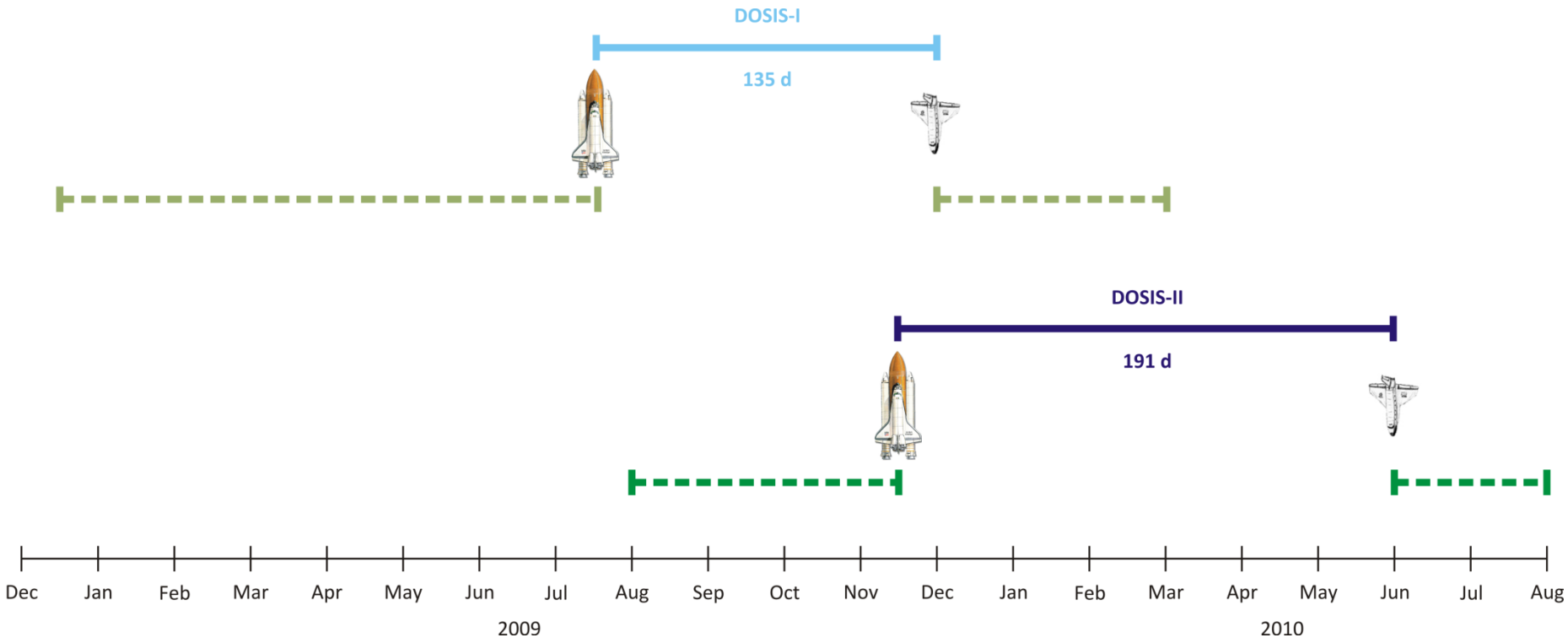
DOSIS-II: HTR method

	TLD-600		TLD-700	
PDP	HTR	σ	HTR	σ
Box 1	**1.966**	0.293	**1.385**	0.013
Box 2	**1.795**	0.079	**1.379**	0.029
Box 3	**1.923**	0.084	**1.350**	0.040
Box 4	**1.962**	0.133	**1.380**	0.027
Box 5	**2.069**	0.160	**1.377**	0.033
Box 6	**1.847**	0.045	**1.341**	0.029
Box 7	**1.919**	0.122	**1.412**	0.015
Box 8	**1.796**	0.052	**1.377**	0.030
Box 9	**1.832**	0.090	**1.373**	0.040
Box 10	**1.937**	0.084	**1.357**	0.022
Box X	**1.799**	0.083	**1.366**	0.018

DOSIS-II: HTR method



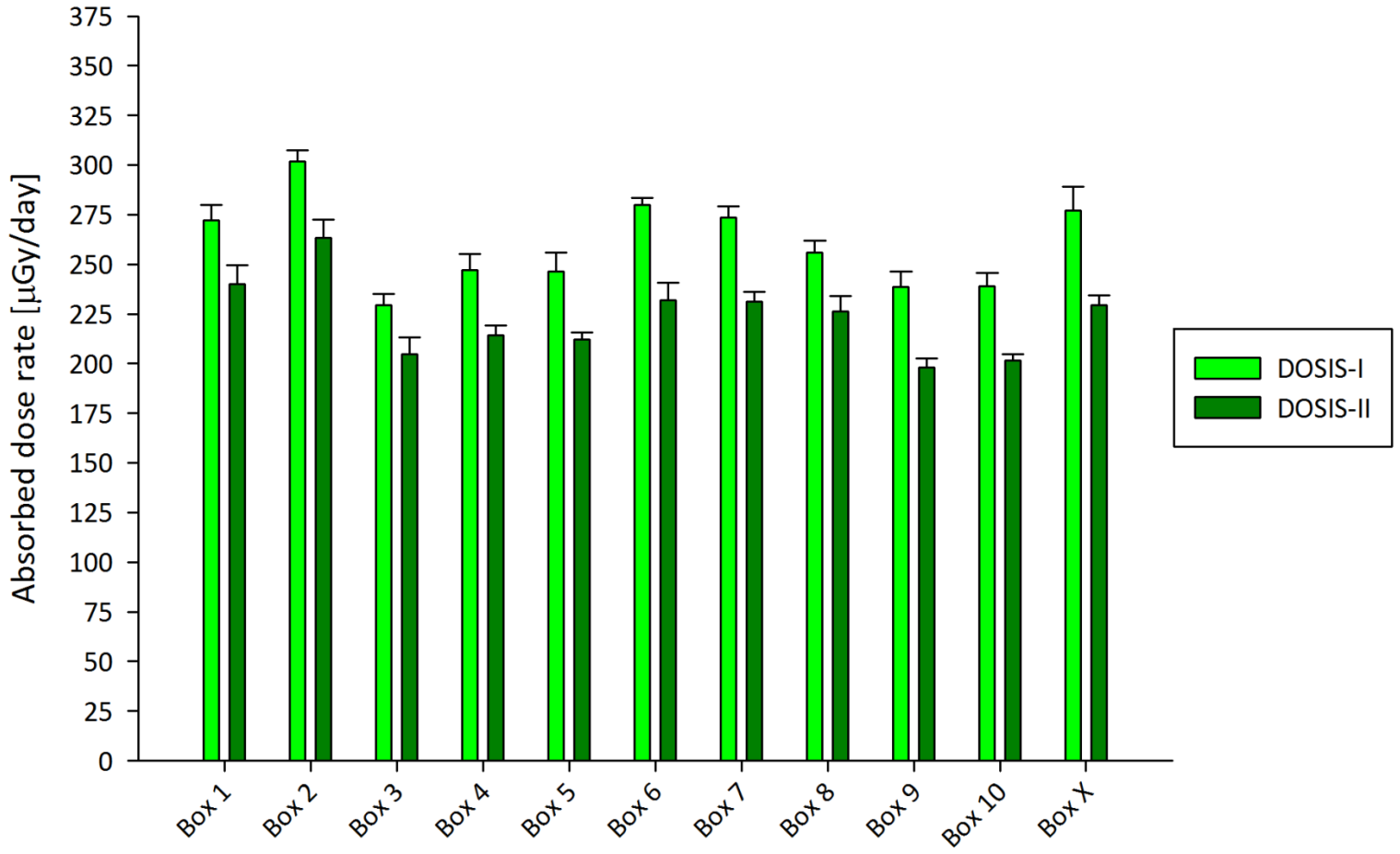
Comparison of DOSIS-I and DOSIS-II



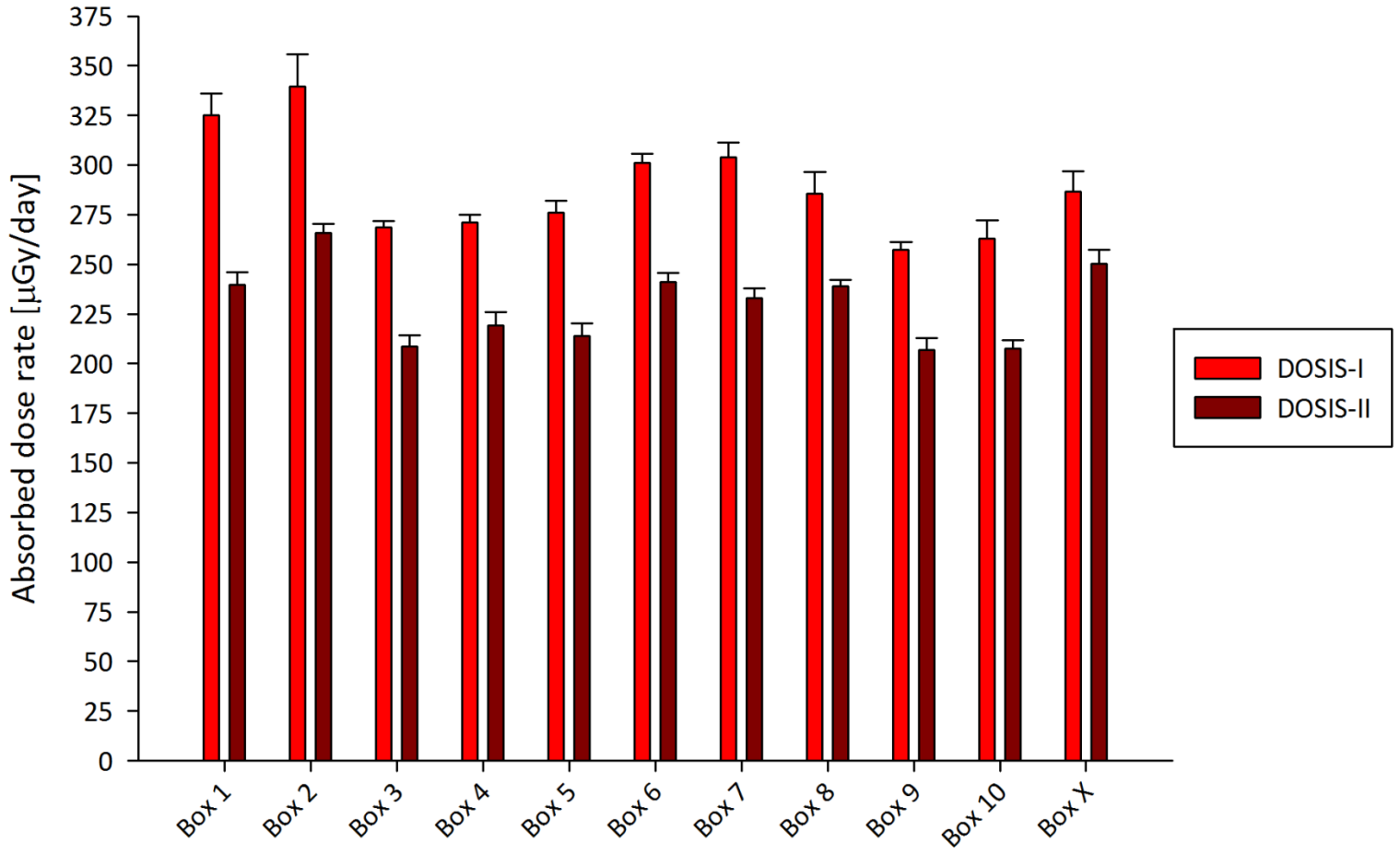
DOSIS-I vs DOSIS-II: Absorbed dose rate

	DOSIS-I		DOSIS-II		DOSIS-I		DOSIS-II		DOSIS-I		DOSIS-II	
PDP	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]
Box 1	**272.1**	8.0	**240.1**	9.5	**324.9**	11.2	**239.8**	6.0	**272.5**	1.9	**233.1**	6.0
Box 2	**301.6**	5.9	**263.3**	9.3	**339.6**	16.1	**265.6**	4.6	**301.2**	6.8	**267.1**	2.9
Box 3	**229.3**	5.9	**204.9**	8.2	**268.7**	3.1	**208.4**	5.6	**238.0**	3.8	**206.8**	5.7
Box 4	**246.9**	8.1	**214.2**	5.0	**271.0**	3.9	**219.2**	6.6	**251.7**	6.7	**217.4**	7.1
Box 5	**246.2**	9.7	**212.3**	3.5	**276.1**	6.1	**214.0**	6.4	**243.0**	6.7	**202.9**	6. 6
Box 6	**279.9**	3.6	**231.8**	8.7	**300.8**	4.7	**241.1**	4.6	**272.1**	4.9	**232.0**	3.9
Box 7	**273.7**	5.6	**231.0**	5.2	**303.7**	7.6	**232.9**	4.9	**274.8**	4.7	**226.0**	8.4
Box 8	**255.9**	5.8	**226.2**	7.6	**285.6**	11.0	**238.9**	3.0	**255.4**	4.7	**225.5**	4.0
Box 9	**238.4**	7.8	**198.0**	4.6	**257.1**	4.0	**206.8**	6.1	**234.6**	5.5	**197.1**	4.1
Box 10	**239.0**	6.7	**201.5**	3.4	**262.8**	9.2	**207.7**	4.2	**238.6**	4.5	**204.8**	6.9
Box X	**277.0**	12.1	**229.5**	4.8	**286.4**	10.4	**250.1**	7.4	**279.1**	5.0	**244.7**	6.1
	TLD-300				**TLD-600**				**TLD-700**			

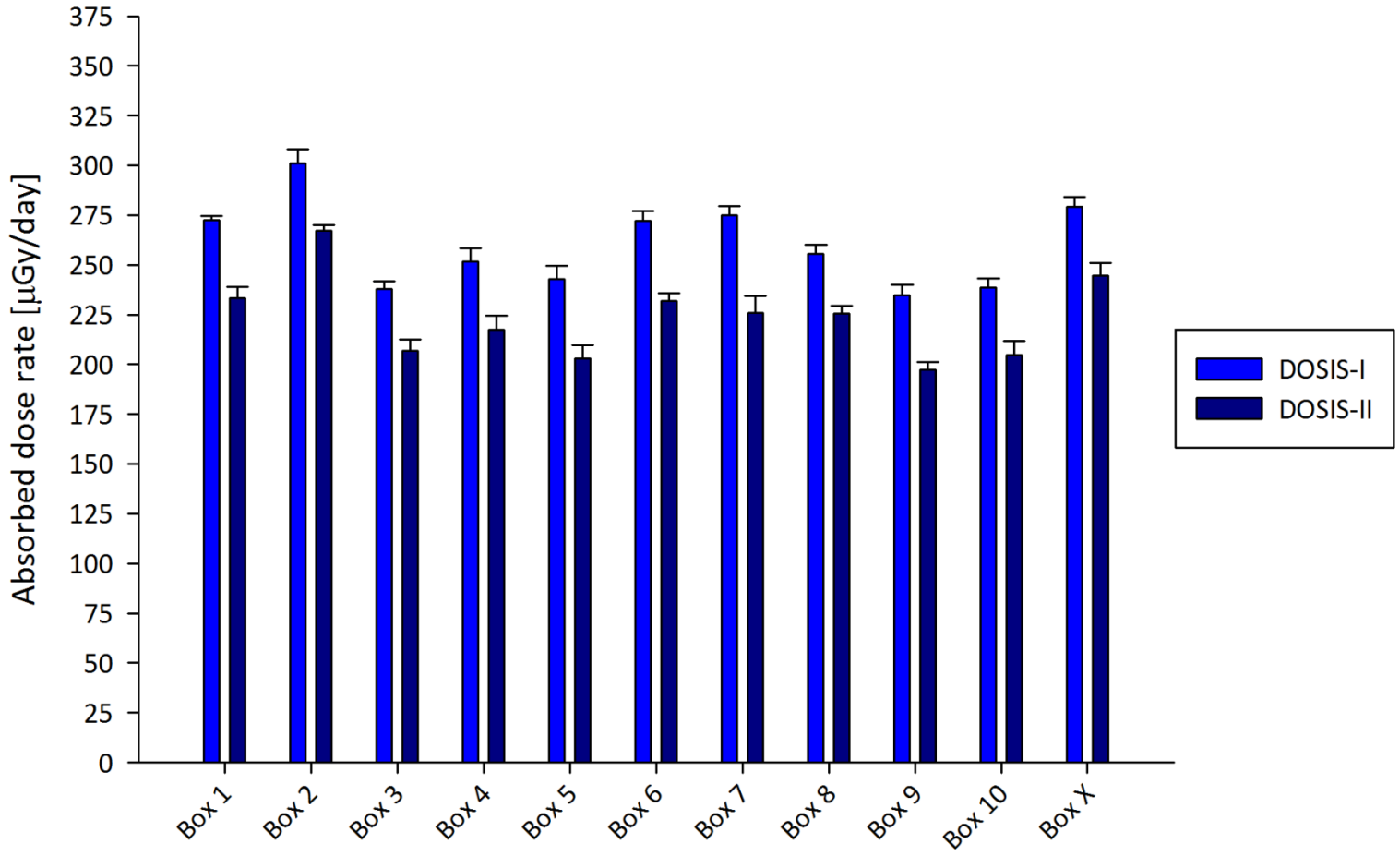
DOSIS-I vs DOSIS-II: Absorbed dose rate TLD-300



DOSIS-I vs DOSIS-II: Absorbed dose rate TLD-600



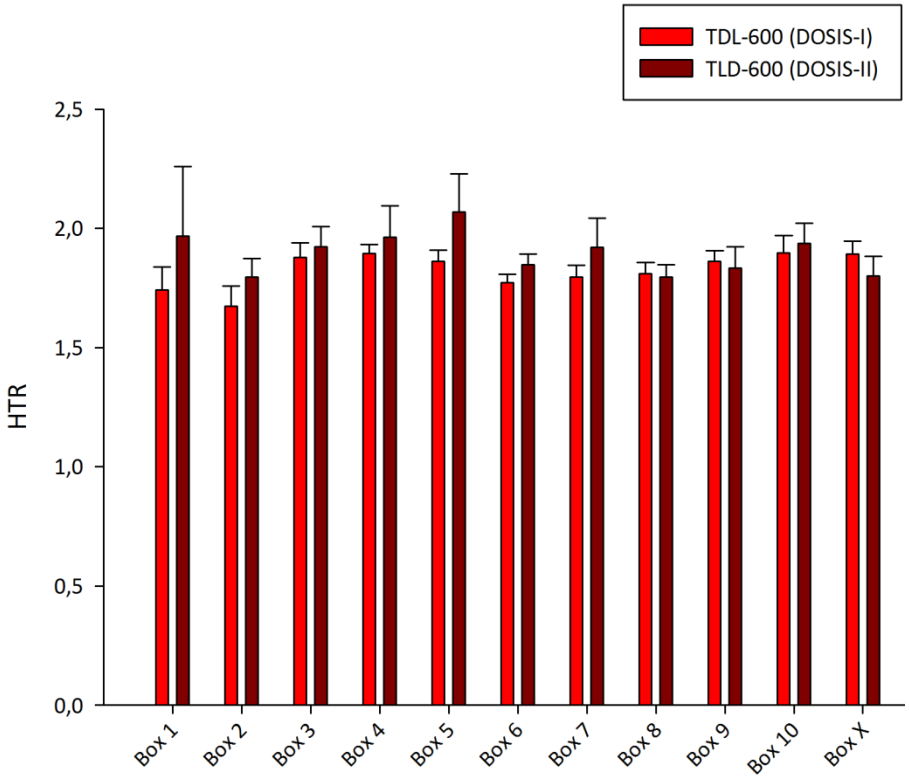
DOSIS-I vs DOSIS-II: Absorbed dose rate TLD-700

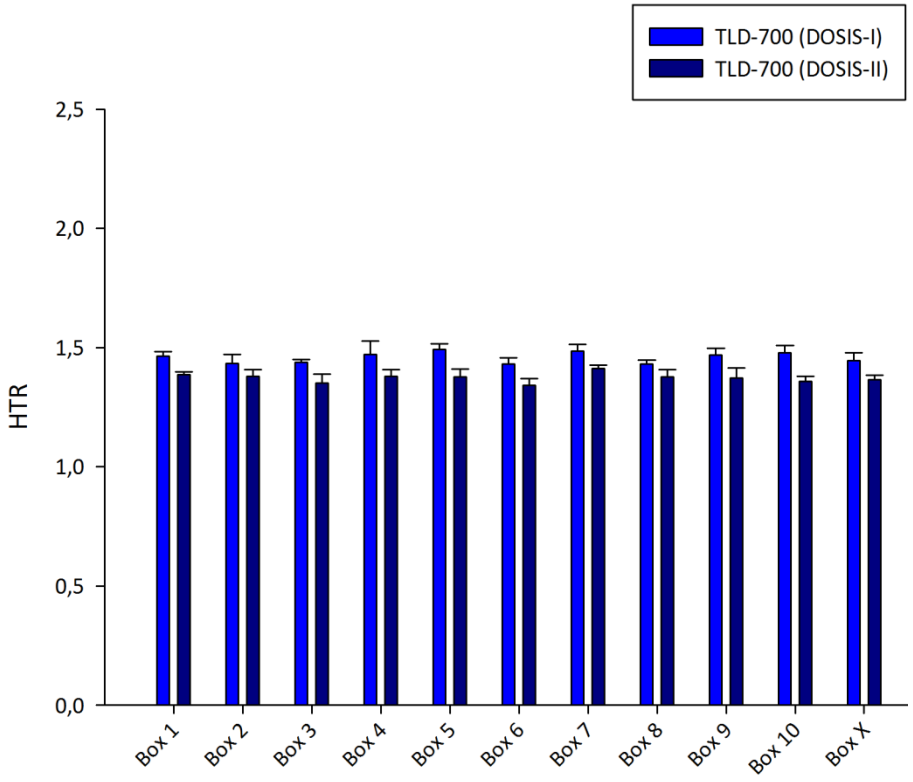


DOSIS-I vs DOSIS-II: HTR

	DOSIS-I (TLD-600)		DOSIS-II (TLD-600)		DOSIS-I (TLD-700)		DOSIS-II (TLD-700)	
	HTR	σ	HTR	σ	HTR	σ	HTR	σ
Box 1	**1.741**	0.096	**1.966**	0.293	**1.463**	0.018	**1.385**	0.013
Box 2	**1.673**	0.085	**1.795**	0.079	**1.433**	0.037	**1.379**	0.029
Box 3	**1.878**	0.060	**1.923**	0.084	**1.437**	0.012	**1.350**	0.040
Box 4	**1.895**	0.036	**1.962**	0.133	**1.471**	0.055	**1.380**	0.027
Box 5	**1.862**	0.046	**2.069**	0.160	**1.491**	0.023	**1.377**	0.033
Box 6	**1.772**	0.034	**1.847**	0.045	**1.431**	0.024	**1.341**	0.029
Box 7	**1.796**	0.049	**1.919**	0.122	**1.486**	0.027	**1.412**	0.015
Box 8	**1.808**	0.049	**1.796**	0.052	**1.431**	0.016	**1.377**	0.030
Box 9	**1.861**	0.045	**1.832**	0.090	**1.467**	0.030	**1.373**	0.040
Box 10	**1.897**	0.073	**1.937**	0.084	**1.478**	0.030	**1.357**	0.022
Box X	**1.892**	0.055	**1.799**	0.083	**1.444**	0.033	**1.366**	0.018

DOSIS-I vs DOSIS-II: HTR





Comparison of ATI and DLR data

- Absorbed dose rate (TLD-300, TLD-600, TLD-700)
  - DOSIS-I results
  - DOSIS-II results
- Mean absorbed dose rate (ATI & DLR)
  - DOSIS-I vs DOSIS-II

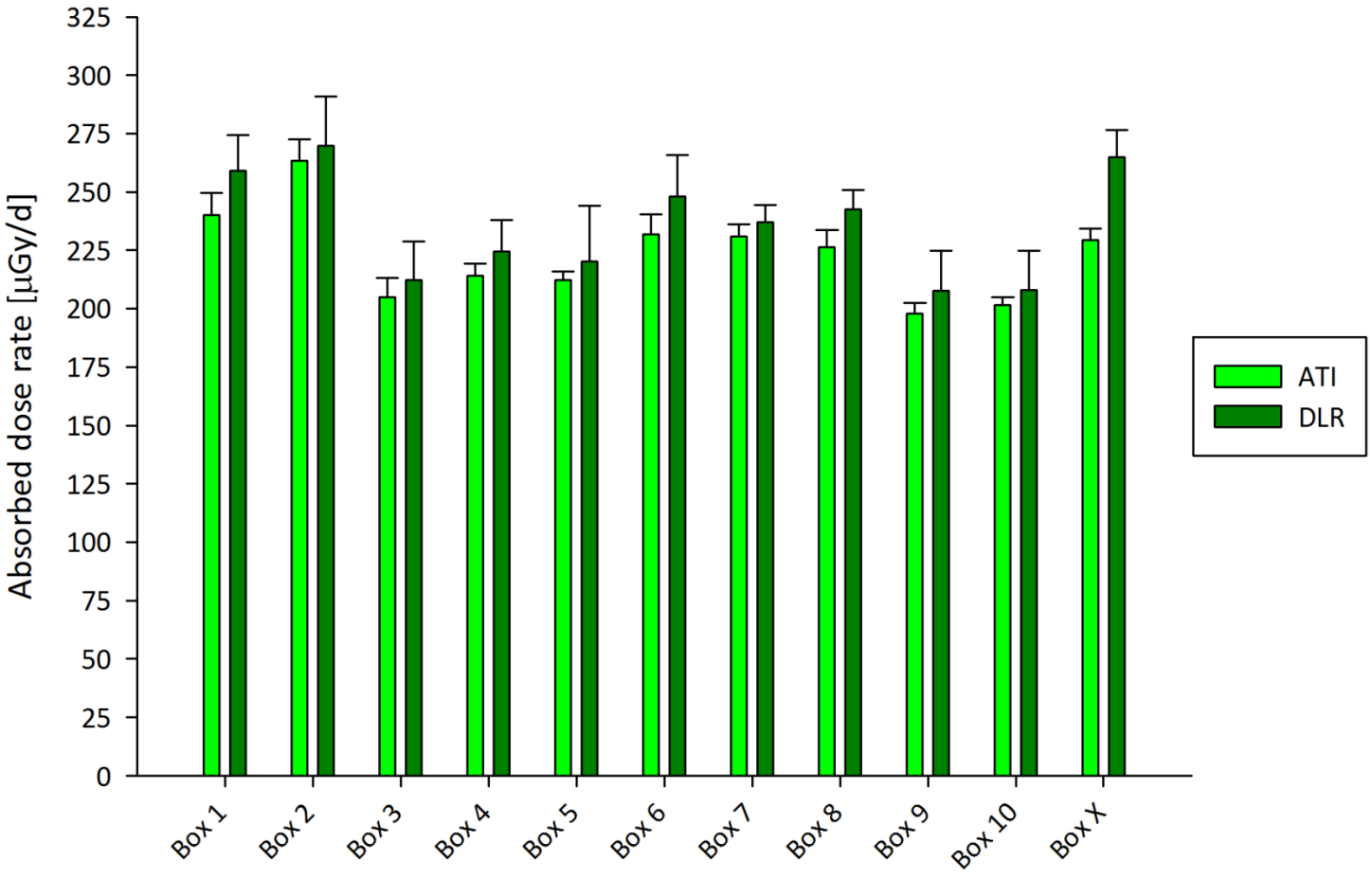
DOSIS-I (ATI vs DLR): Absorbed dose rate

	ATI		DLR		ATI		DLR		ATI		DLR	
PDP	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{tot}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{tot}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{tot}/t_{L-R} [µGy/d]	σ [µGy/d]
Box 1	**272.1**	8.0	**265.4**	8.8	**324.9**	11.2	**279.7**	4.6	**272.5**	1.9	**256.8**	1.7
Box 2	**301.6**	5.9	**294.7**	6.2	**339.6**	16.1	**305.0**	6.2	**301.2**	6.8	**297.3**	4.9
Box 3	**229.3**	5.9	**229.9**	7.2	**268.7**	3.1	**247.6**	5.7	**238.0**	3.8	**228.0**	3.6
Box 4	**246.9**	8.1	**234.0**	5.6	**271.0**	3.9	**244.2**	2.4	**251.7**	6.7	**235.8**	2.4
Box 5	**246.2**	9.7	**236.8**	4.3	**276.1**	6.1	**245.4**	6.6	**243.0**	6.7	**231.5**	3.3
Box 6	**279.9**	3.6	**271.5**	4.2	**300.8**	4.7	**277.9**	6.0	**272.1**	4.9	**260.9**	5.6
Box 7	**273.7**	5.6	**270.2**	6.8	**303.7**	7.6	**266.2**	3.9	**274.8**	4.7	**254.6**	2.4
Box 8	**255.9**	5.8	**255.1**	5.9	**285.6**	11.0	**262.7**	10.8	**255.4**	4.7	**243.9**	5.4
Box 9	**238.4**	7.8	**221.7**	4.8	**257.1**	4.0	**241.2**	3.5	**234.6**	5.5	**222.7**	3.7
Box 10	**239.0**	6.7	**236.4**	2.2	**262.8**	9.2	**238.5**	5.6	**238.6**	4.5	**224.3**	4.5
Box X	**277.0**	12.1	**264.3**	5.3	**286.4**	10.4	**278.6**	8.9	**279.1**	4.9	**249.3**	6.4
	TLD-300				TLD-600				TLD-700			

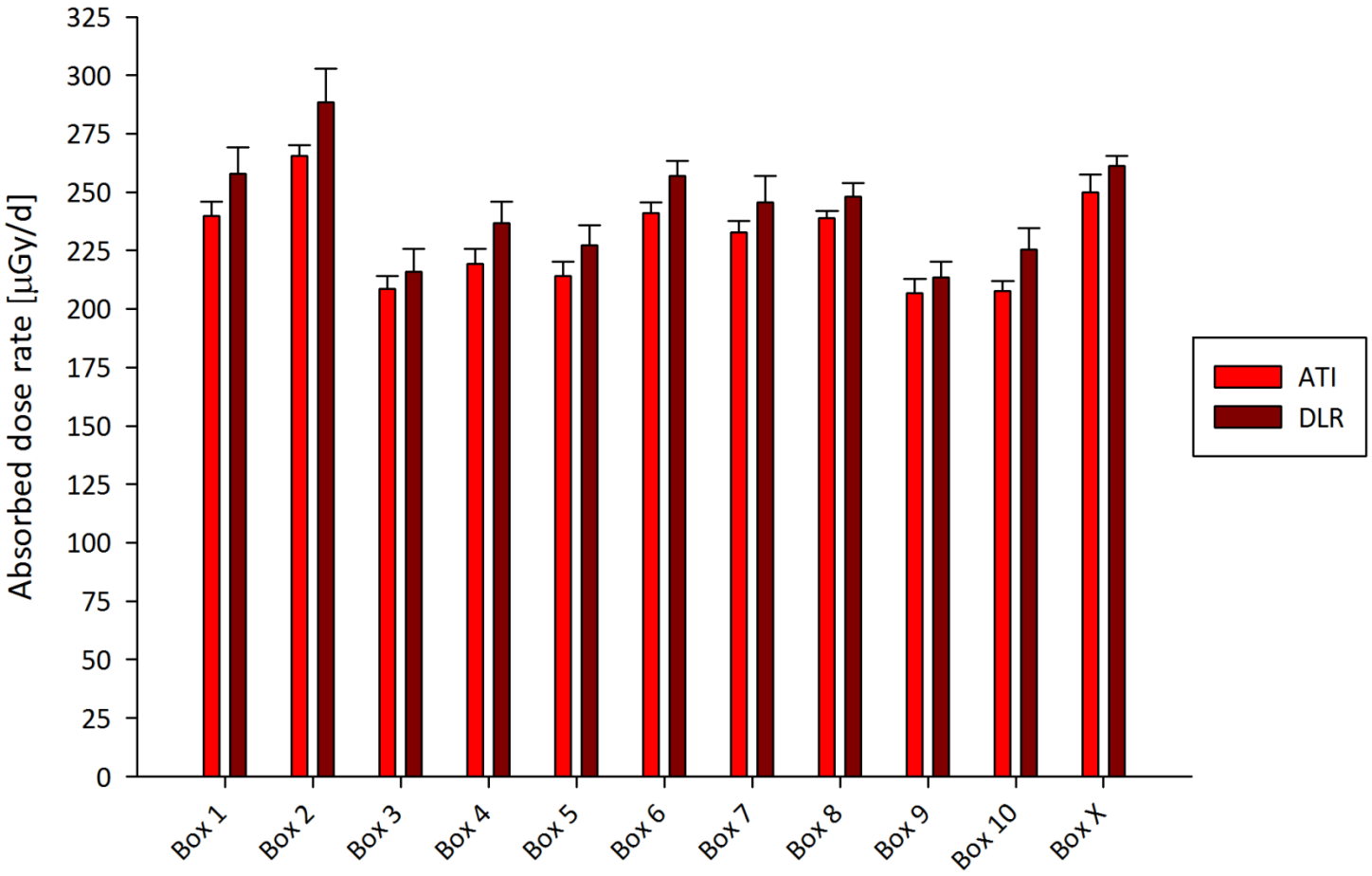
DOSIS-II (ATI vs DLR): Absorbed dose rate

	ATI		DLR		ATI		DLR		ATI		DLR	
PDP	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{tot}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{tot}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{corr}/t_{L-R} [µGy/d]	σ [µGy/d]	D_{tot}/t_{L-R} [µGy/d]	σ [µGy/d]
Box 1	**240.1**	9.5	**259.2**	15.0	**239.8**	6.0	**257.8**	11.5	**233.1**	6.0	**244.7**	6.8
Box 2	**263.3**	9.3	**269.8**	21.1	**265.6**	4.6	**288.5**	14.3	**267.1**	2.9	**271.7**	12.0
Box 3	**204.8**	8.2	**212.3**	16.3	**208.4**	5.6	**216.0**	9.8	**206.8**	5.7	**209.5**	8.7
Box 4	**214.2**	5.0	**224.5**	13.6	**219.2**	6.6	**236.6**	9.3	**217.4**	7.1	**221.1**	5.6
Box 5	**212.3**	3.5	**220.1**	23.9	**213.9**	6.4	**227.3**	8.5	**202.9**	6.6	**211.0**	6.1
Box 6	**231.8**	8.6	**248.1**	17.6	**241.1**	4.6	**256.8**	6.5	**232.0**	3.9	**243.3**	6.1
Box 7	**231.0**	5.2	**237.2**	7.0	**232.9**	4.9	**245.5**	11.5	**226.0**	8.4	**235.7**	5.3
Box 8	**226.2**	7.6	**242.5**	8.3	**238.9**	3.0	**248.1**	5.7	**225.5**	4.0	**220.5**	6.5
Box 9	**198.0**	4.6	**207.5**	17.3	**206.8**	6.1	**213.5**	6.8	**197.1**	4.1	**205.2**	4.6
Box 10	**201.5**	3.4	**208.0**	16.9	**207.7**	4.2	**225.3**	9.4	**204.8**	6.9	**211.1**	6.8
Box X	**229.5**	4.8	**265.0**	11.6	**250.0**	7.4	**261.3**	4.1	**244.7**	6.1	**246.5**	7.0
	TLD-300				TLD-600				TLD-700			

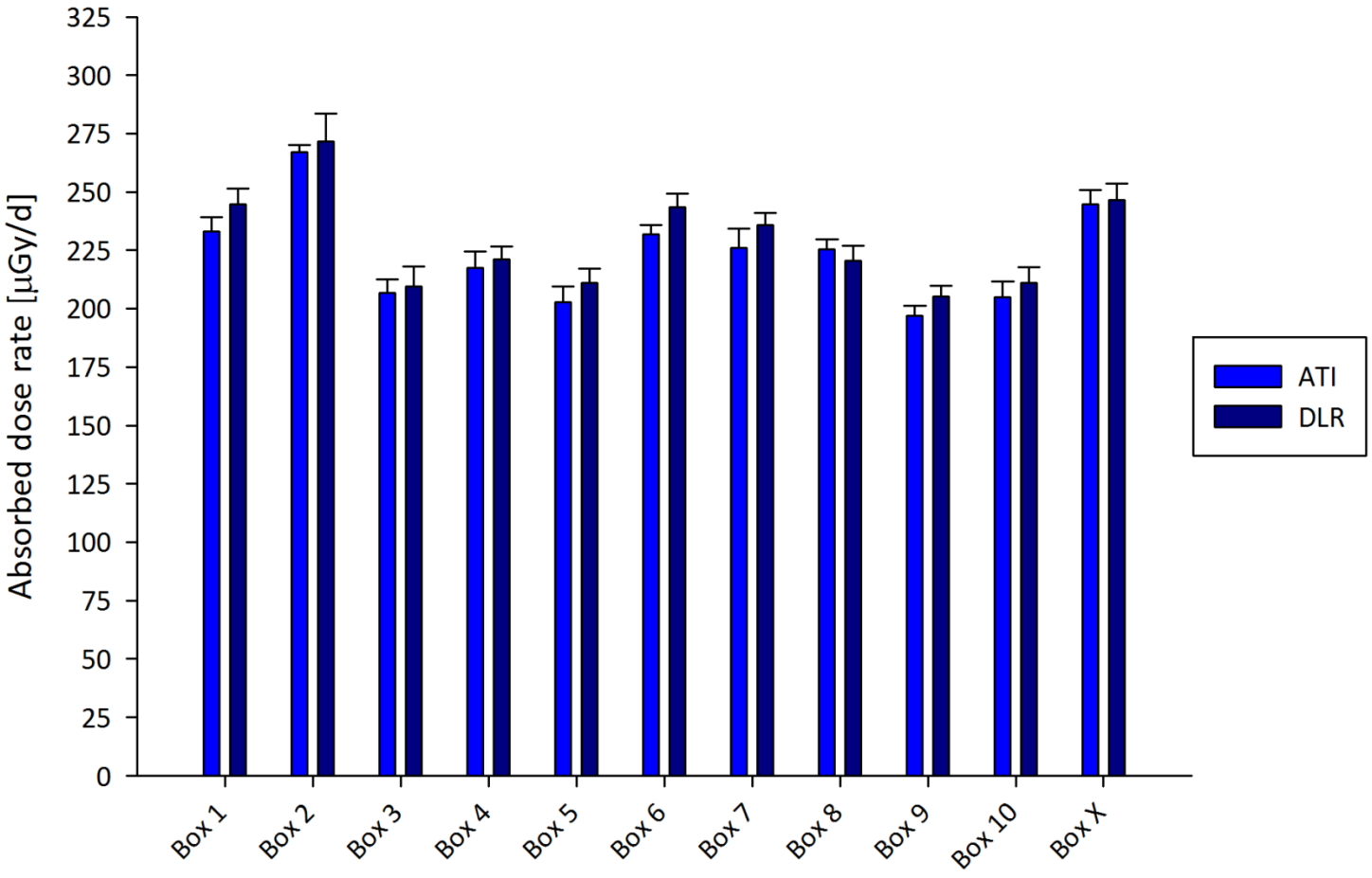
DOSIS-II (ATI vs DLR): Absorbed dose rate TLD-300



DOSIS-II (ATI vs DLR): Absorbed dose rate TLD-600



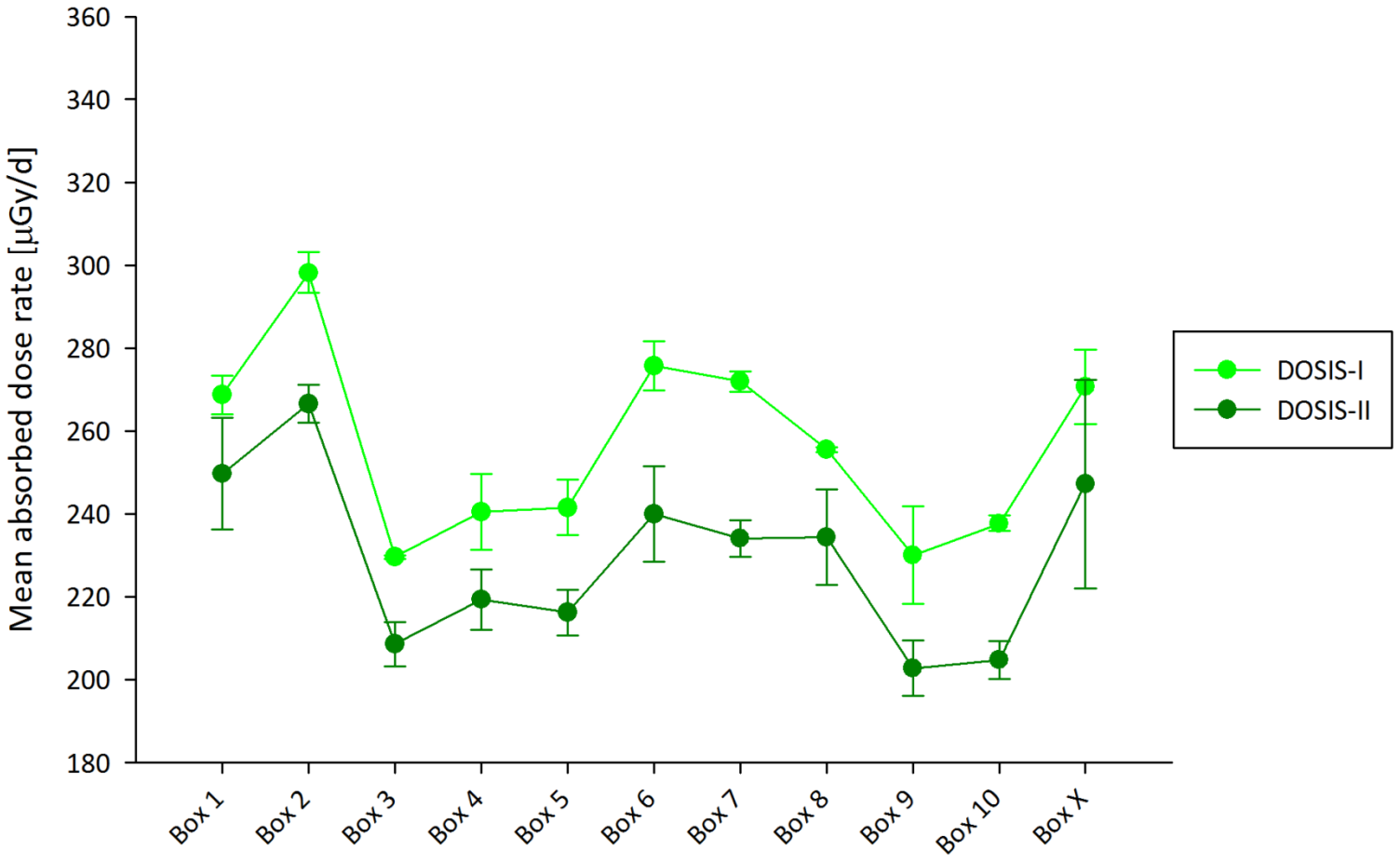
DOSIS-II (ATI vs DLR): Absorbed dose rate TLD-700



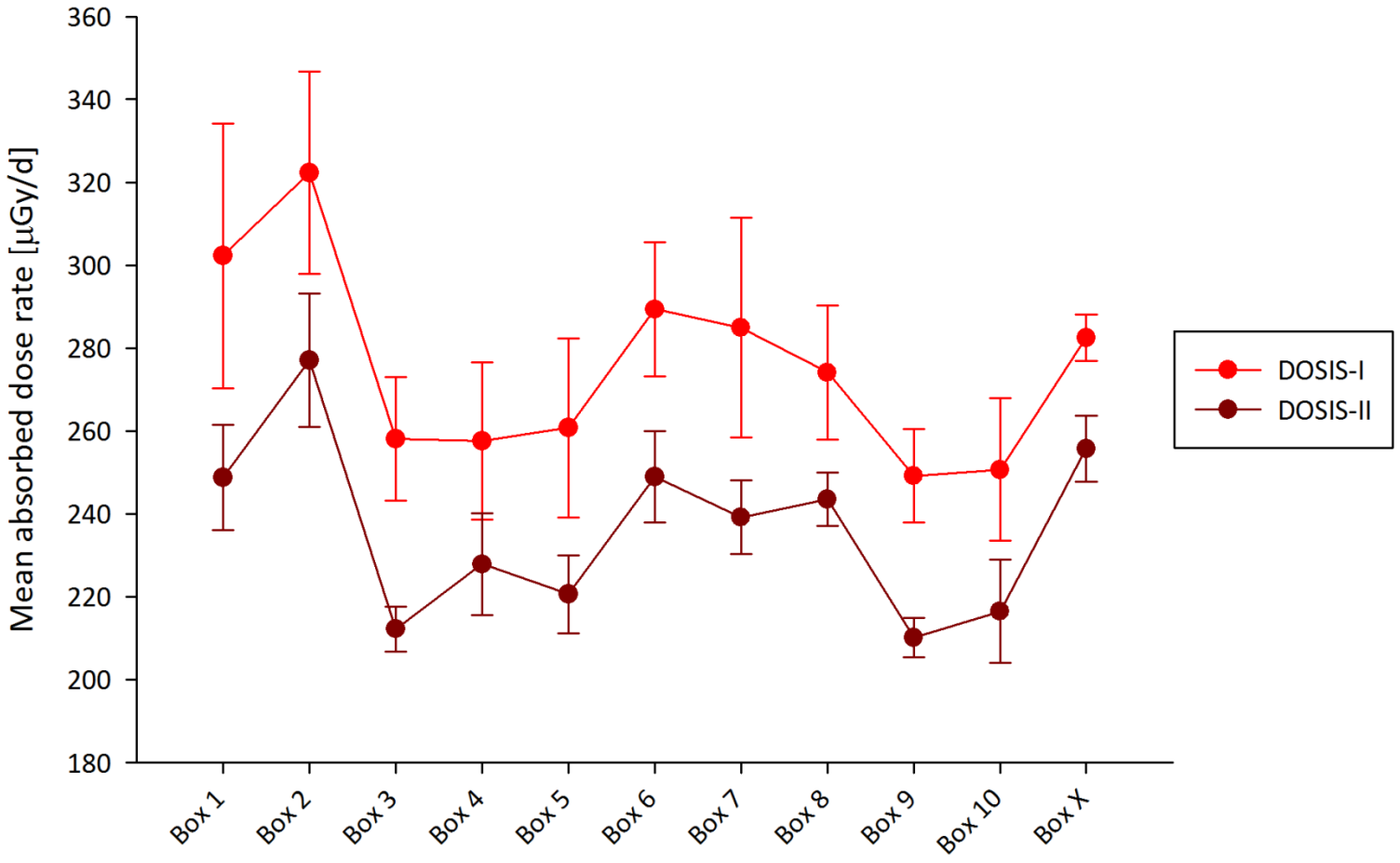
DOSIS-I vs DOSIS-II: Mean absorbed dose rate

	DOSIS-I		DOSIS-II		DOSIS-I		DOSIS-II		DOSIS-I		DOSIS-II	
PDP	D/t_{L-R} [µGy/d]	σ [µGy/d]	D/t_{L-R} [µGy/d]	σ [µGy/d]	D/t_{L-R} [µGy/d]	σ [µGy/d]	D/t_{L-R} [µGy/d]	σ [µGy/d]	D/t_{L-R} [µGy/d]	σ [µGy/d]	D/t_{L-R} [µGy/d]	σ [µGy/d]
Box 1	**268.7**	4.70	**249,7**	13,5	**302.28**	31.93	**248,8**	12,7	**264.63**	11.07	**238,9**	8,2
Box 2	**298.2**	4.89	**266,6**	4,6	**322.30**	24.47	**277,1**	16,2	**299.24**	2.74	**269,4**	3,3
Box 3	**229.6**	0.44	**208,6**	5,3	**258.13**	14.89	**212,2**	5,4	**232.98**	7.04	**208,1**	1,9
Box 4	**240.5**	9.12	**219,4**	7,3	**257.59**	18.94	**227,9**	12,3	**243.74**	11.22	**219,3**	2,6
Box 5	**241.5**	6.68	**216,2**	5,5	**260.73**	21.68	**220,6**	9,4	**237.23**	8.10	**206,9**	5,7
Box 6	**275.7**	5.92	**240,0**	11,5	**289.36**	16.20	**249,0**	11,1	**266.50**	7.91	**237,6**	8,0
Box 7	**271.9**	2.45	**234,1**	4,4	**284.95**	26.51	**239,2**	8,9	**264.71**	14.30	**230,9**	6,8
Box 8	**255.5**	0.57	**234,4**	11,5	**274.13**	16.16	**243,5**	6,5	**249.64**	8.11	**223,0**	3,6
Box 9	**230.1**	11.82	**202,8**	6,7	**249.15**	11.24	**210,1**	4,7	**228.65**	8.41	**201,1**	5,7
Box 10	**237.7**	1.85	**204,8**	4,6	**250.67**	17.20	**216,5**	12,5	**231.46**	10.13	**208,0**	4,4
Box X	**270.6**	8.97	**247,2**	25,1	**282.52**	5.54	**255,7**	8,0	**264.22**	21.09	**245,6**	1,3

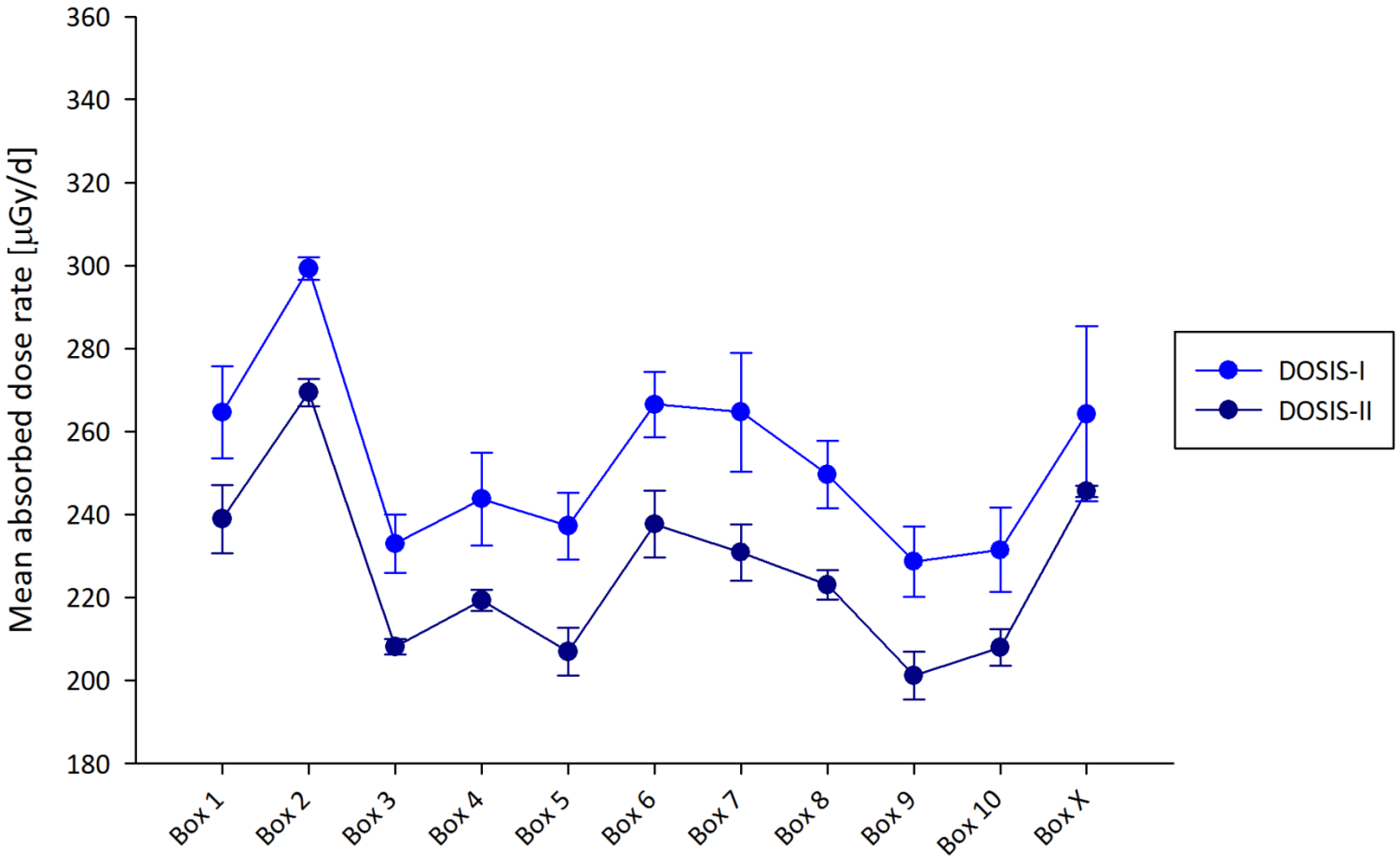
DOSIS-I vs DOSIS-II: Mean absorbed dose rate TLD-300



DOSIS-I vs DOSIS-II: Mean absorbed dose rate TLD-600

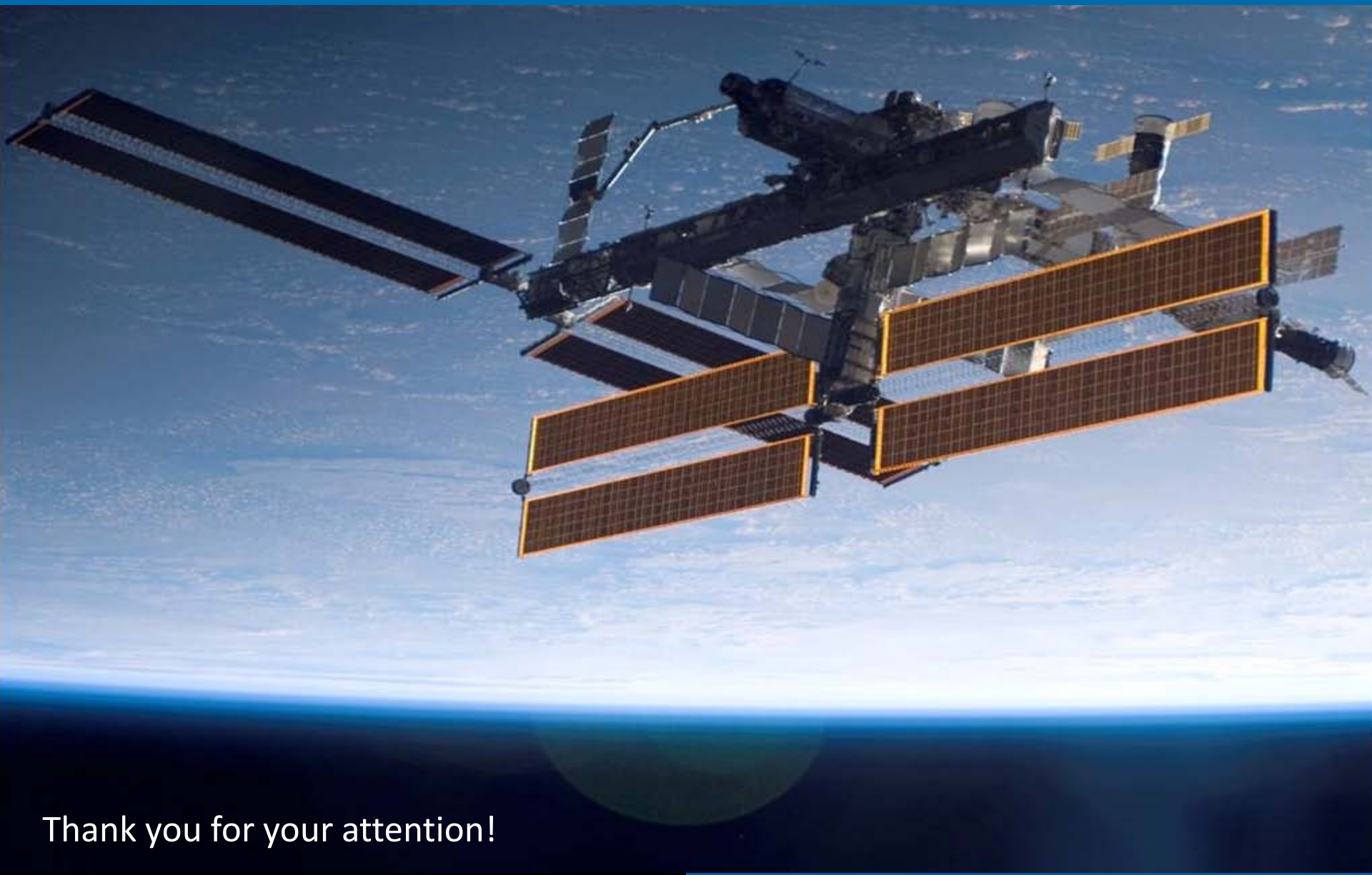


DOSIS-I vs DOSIS-II: Mean absorbed dose rate TLD-700



Conclusions

- Same pattern of dose distribution for DOSIS-I and DOSIS-II
- Compared to DOSIS-I, dose rates measured for DOSIS-II are on average lower by 13%
- Preliminary results from ATI and DLR are largely consistent within statistical uncertainty
- Need for further studies of TL efficiency for different radiation qualities
  - Applied detectors from different manufacturer's batches
  - Ground-based experiments at HIMAC (Boxes Y, Z)
  - Scheduled neutron irradiations at ATI (Boxes Y, Z)



Thank you for your attention!