

Dosimetry and LET spectrometry onboard ISS with TLD's and LET spectrometers exposed during 2007 year.

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Goals of studies

- To determine dosimetric characteristics measured onboard International Space Station (ISS) with passive detectors and analysed them;
- To obtain other data on the exposure level and its inside station variations;
- Actuality of study: necessity to improve the accuracy of determination of the spacecraft crew members exposure level

Methods of studies

Detectors used:

1. Thermoluminescent detectors:

- LiF (TLD100) (IBMP),
- $\text{Al}_2\text{O}_3:\text{C}$, $\text{CaSO}_4:\text{Dy}$, and AIP glass (NPI);

2. Track etch detectors (TED) (NPI):

polyallyldiglycolcarbonates (PADC) available from

- Page Mouldings Ltd.,
- Track Analysis Systems, Ltd (NPI); and
- American Technical Plastics (USF4)

Onboard ISS flight conditions



- Delivery to ISS: «Progress M-360» cargo boat, 12th May 2007
- Return: together with other cargo from the crew of MKS-15 expedition onboard «Soyuz-TMA10»; 22th October 2007
- Delivery to IBMP: beginning of November 2007
- Full exposure time: 163 days
- Average flight altitude – 345 km

External view of the setting and individual SPD set



During cosmic expedition «Matroshka-R» 6 sets of SPD have been used, with dimensions – 118 x 63 x 43 mm; weight less than 0.450 kg ; another SPD with NPI passive detectors has been exposed during SI 2 experiment

Positioning of SPD boxes in Russian Module (RM) of ISS

SPD box #	Coordinates [cm] (x, y, z)	Panel #	Averaged shielding [g/cm ²]	Standard deviation [g/cm ²]
SPD-1	(327, -54, 48)	102 Piers Module 1, floor	35.2	34
SPD-2	(301, 37, -43)	401 Piers Module 1, the star board	34.8	32
SPD-3	(786, 135, -108)	325 SM, cone, ceiling, close to R-16	47.9	42
SPD-4	(1216, 22, -81)	461 SM, the star board	32.3	42
SPD-5	(786, 129, 97)	323 SM, cone, ceiling, close to R-16	41.4	37
SPD-6	(317, 54, 27)	305 SM, ceiling, small diameter	33.1	31

Remark – position of SI 2 SPD with NPI detectors will be specified later

RESULTS – Thermoluminescent detectors

Materials of TLDs

IBMP:

- LiF, Harshaw TLD 100, detection threshold (DT) for photons: $\sim 10 \mu\text{Sv}$

NPI:

- $\text{Al}_2\text{O}_3:\text{C}$, DT for photons: $\sim 1 \mu\text{Sv}$;
- Czech alumophosphate TL glasses (Al-P glass), DT for photons: $\sim 10 \mu\text{Sv}$;
- $\text{CaSO}_4:\text{Dy}$, detection threshold (DT) for photons: $\sim 1 \mu\text{Sv}$

Interpretation procedure – calibration performed in ^{60}Co photon etalon beams in K_{air} ; readings transformed to D_{tissue}

Results of the TLD's evaluation SPDs - RM

SPD No.	$D_{\text{tissue}}, \mu\text{Gy/day}$		
	TLD 100	$\text{Al}_2\text{O}_3:\text{C}$	AlP glass
41	310 ± 110	220 ± 30	250 ± 40
42	250 ± 90	120 ± 30	190 ± 30
43	210 ± 80	160 ± 30	165 ± 30
44	250 ± 90	140 ± 30	150 ± 30
45	170 ± 60	- ¹⁾	- ¹⁾
46	160 ± 60	120 ± 20	195 ± 30

¹⁾ not returned

Remarks:

1. Values not corrected for high-LET radiation contributions (lower for $\text{Al}_2\text{O}_3:\text{C}$ than for other two)
2. Uncertainties on 95 % confidence level
3. Variability up to the factor ~ 2

Results of the TLD's evaluation – SI 2

Position	K_{air} $\mu\text{Gy/day}$		D_{tissue} $\mu\text{Gy/day}$		$H^*(10)$ $\mu\text{Sv/day}$	
	$\text{Al}_2\text{O}_3:\text{C}$	$\text{CaSO}_4:\text{Dy}$	$\text{Al}_2\text{O}_3:\text{C}$	$\text{CaSO}_4:\text{Dy}$	$\text{Al}_2\text{O}_3:\text{C}$	$\text{CaSO}_4:\text{Dy}$
top	167±10	143±12	184±13	157±12	193±14	165±12
bottom	175±9	140±10	193±10	154±12	202±11	159±13

Remarks:

- Values not corrected for high-LET radiation contributions
- Uncertainties on 67 % confidence level

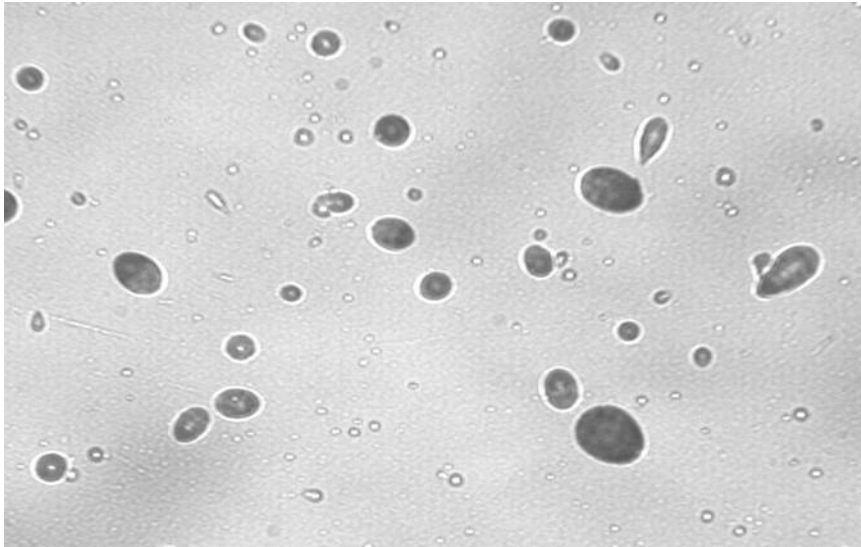
LET spectrometer based on a PADDC track-etch detectors

- Polyallyldiglycolcarbonate (PADDC)– $C_{12}H_{18}O_7$
 - Page 0.5 mm (Page Mouldings Ltd, England),
 - Tastrak 0.5 mm (Track Analysis Systems Ltd, Bristol)
 - USF 4 0.6 mm (American Technical Plastics)
- etching in 5 N NaOH at 70°C for 18 hours
- automatic optical image analyzer LUCIA G
- track parameters => determination of the ratio V_T/V_B (V_T – etch rate of damaged material, V_B – etch rate of unaffected bulk material) => LET
- range covered: ~ 10 to 700 keV/ μ m; 1 – 100 mSv

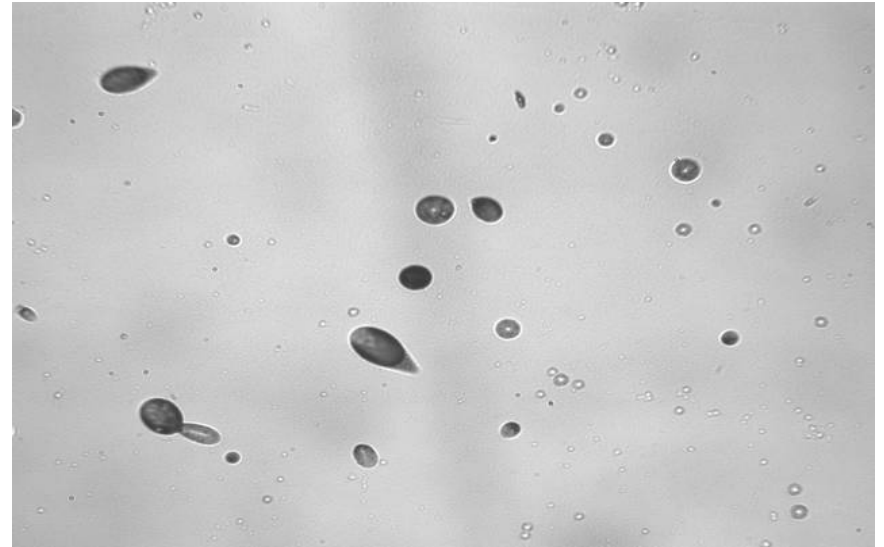
Calibration

- LET = $f(V)$
- irradiation in heavy charged particle beams at
 - ❖ HIMAC (NIRS Chiba, Japan) in the frame of ICCHIBAN programs – ICCHIBAN 2, 4, 6, and 8;
 - ❖ NASA Space Radiation Laboratory (Brookhaven National Laboratory) in the frame of ICCHIBAN BNL;
 - ❖ Nuclotron of the Laboratory of High Energies, JINR, Dubna
- particles: ^{12}C – ^{84}Kr , LET ~ 7.5 – 600 keV/ μm
- detection thresholds: Page ~ 10 keV/ μm , Tastrak ~ 15 keV/ μm ; USF4 – close to Page

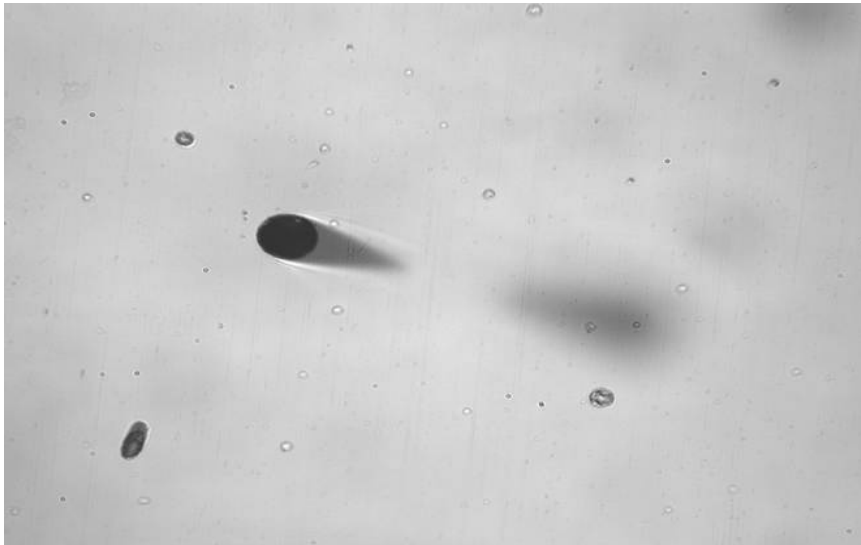
Examples of etched tracks



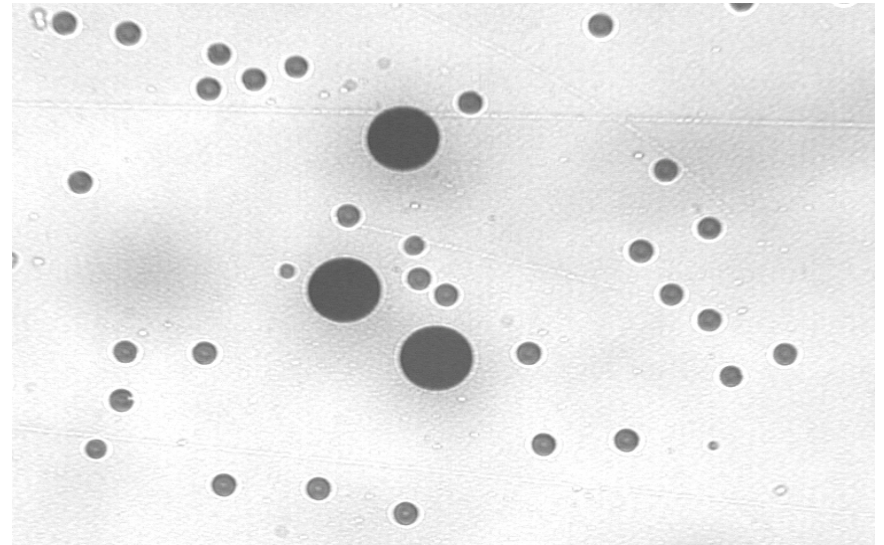
Matryoshka – 9 months on ISS



SPD boxes – 5 months on ISS - 1

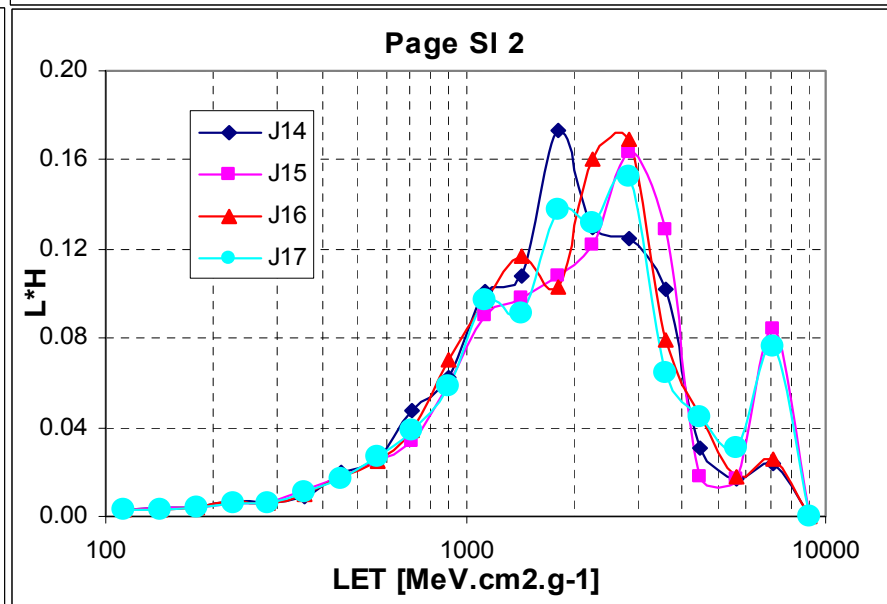
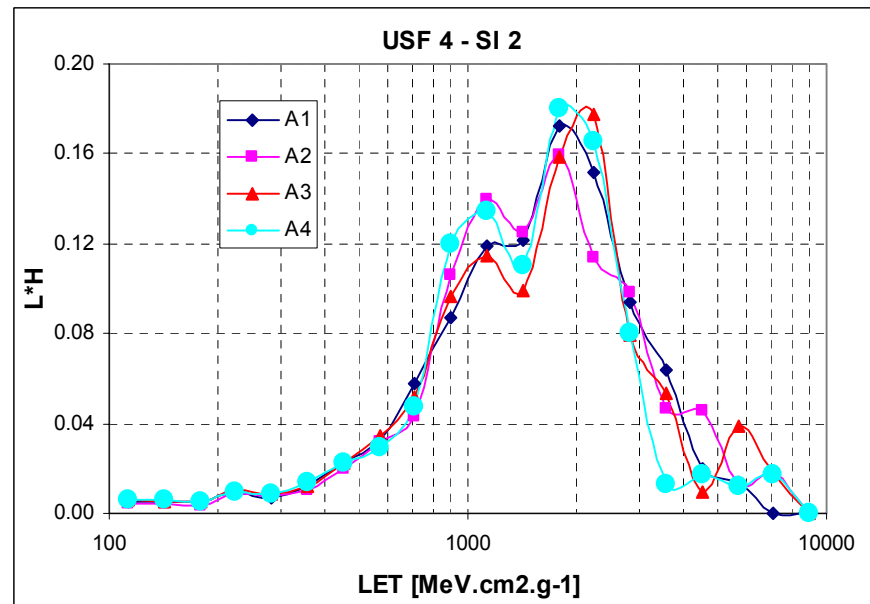
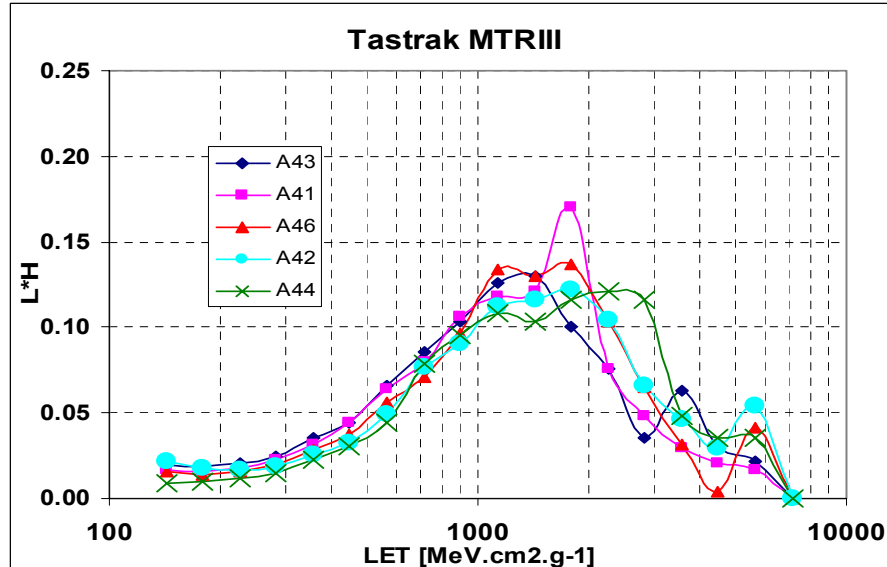
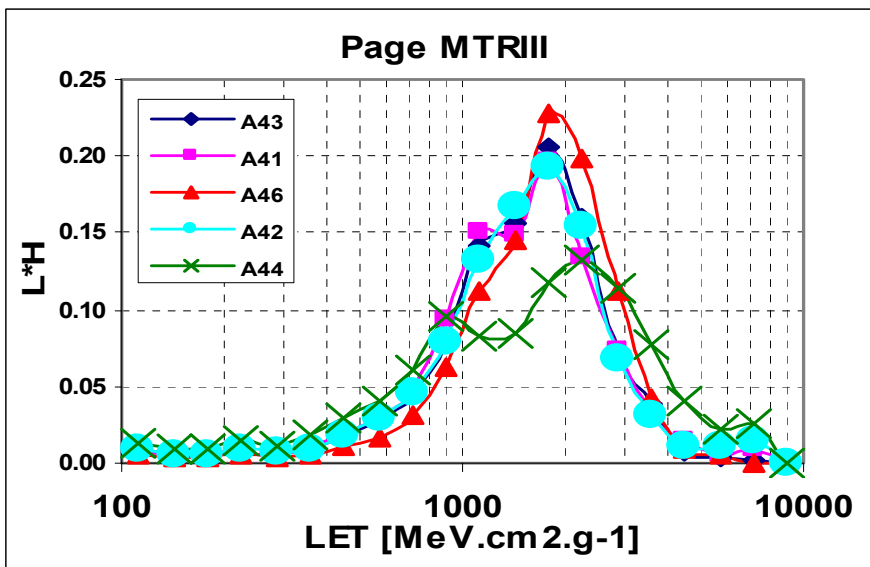


SPD boxes – 5 months on ISS - 2



^{16}O (20) and ^{56}Fe (402 keV/ μm)

Relative microdosimetry distributions of D and H in LET



Results of the TED's evaluation – SPDs - RM

SPD No.	D_{LET} , $\mu\text{Gy/day}$		H_{LET} , $\mu\text{Sv/day}$	
	Page	Tastrak	Page	Tastrak
41	42 ± 4	19 ± 2	428 ± 50	184 ± 24
42	28 ± 3	24 ± 3	275 ± 31	218 ± 28
43	40 ± 5	16 ± 2	376 ± 42	141 ± 16
44	26 ± 3	19 ± 2	197 ± 23	215 ± 25
46	35 ± 4	13 ± 2	390 ± 45	135 ± 16

Remarks:

1. Uncertainties on 67 % confidence level
2. Variability up to the factor more than ~ 2
3. Values for Tastrak about 45 % lower than for Page, a little too much for slight difference of LET thresholds (10, resp. 15 keV/ μm) (ageing effect? - detectors stored at Moscow more than 3 years before the exposure)

Results of the TED's evaluation – SI 2

Position	D_{LET} $\mu\text{Gy/day}$		H_{LET} $\mu\text{Sv/day}$	
	Page	USF 4	Page	USF 4
top	30.4 ± 1.4	-	350 ± 14	-
middle - 1	30.8 ± 1.2	29.3 ± 1.3	371 ± 16	269 ± 12
middle - 2	29.2 ± 1.2	27.7 ± 1.2	355 ± 15	277 ± 12
middle - 3	27.5 ± 1.1	32.6 ± 1.4	341 ± 14	284 ± 11
middle - 4	31.3 ± 1.2	36.9 ± 1.6	321 ± 16	313 ± 12
bottom	31.3 ± 1.3	-	347 ± 14	-

Remarks:

1. USF4 calibration – to be still precised.
2. Uncertainties on 67 % confidence level, only statistical

Daily values of dose and/or dose equivalent – SPD 07, Page

SPD No.	D _{low} μGy	D _{high} μGy	H _{high} μSv	D _{total} μGy	H _{total} μSv	QF
41	231	42	428	273	701	2.6±0.4
42	176	28	275	204	479	2.4±0.4
43	155	40	376	195	571	2.9±0.4
44	177	26	197	203	400	2.0±0.3
46	181	35	390	266	606	2.8±0.4

Remarks:

1. Values for AIP-TLD taken for low LET contribution, that of Page for high LET, uncertainties – ± 25 % (2s)
2. Correction of TLD for high LET taken from Page data

Daily values of D and H – SPD 07, Page vs. Tastrak comparison

	Page			Tastrak		
SPD No.	D _{total} μGy	H _{total} μSv	QF	D _{total} μGy	H _{total} μSv	QF
41	273	701	2.6±0.4	250	434	1.7±0.2
42	204	479	2.4±0.4	200	417	2.1±0.3
43	195	571	2.9±0.4	170	311	1.8±0.2
44	203	400	2.0±0.3	196	412	2.1±0.3
46	266	606	2.8±0.4	194	329	1.7±0.2

Remarks:

1. Values for AIP-TLD taken for low LET contribution, – ± 25 % (2s)
2. D for Tastrak by 11 % lower, that of H by 31 %, it would correspond to the contribution of particle with LET between 10 ad 15 keV/μm but – see conditions mentioned

Daily values of dose and/or dose equivalent

– SI 2, Page, 2 TLD's

TLD	Position	D_{TLD} μGy	$D_{\text{CR-39}}$ μGy	D_{total} μGy	$H_{\text{CR-39}}$ μSv	H_{total} μSv	QF
Al_2O_3	top	184 ± 10	31.3 ± 1.2	210 ± 10	350 ± 14	560 ± 18	2.7 ± 0.2
	bottom	193 ± 10	30.4 ± 1.2	216 ± 11	350 ± 15	566 ± 18	2.6 ± 0.2
CaSO_4	top	161 ± 8	31.3 ± 1.2	183 ± 9	347 ± 14	530 ± 16	2.9 ± 0.2
	bottom	155 ± 10	30.4 ± 1.2	177 ± 9	347 ± 15	524 ± 17	2.9 ± 0.2

Daily values of dose and/or dose equivalent

– SI 2, Page, USF4, TLD's, middle samples

No.	CR-39	D _{TLD} μGy	D _{CR-39} μGy	D _{total} μGy	H _{CR-39} μSv	H _{total} μSv	QF
J14	Page	173±12	30.8±1.2	194±12	371±16	565±20	2.9±0.2
A1	USF4	173±12	29.3±1.0	193±12	269±12	462±17	2.4±0.2
J15	Page	173±12	29.2±1.2	193±12	355±15	548±19	2.8±0.2
A2	USF4	173±12	27.7±1.0	191±12	277±13	468±18	2.4±0.2
J16	Page	173±12	27.5±1.1	191±12	341±15	532±19	2.8±0.2
A3	USF4	173±12	32.6±1.1	196±12	284±13	480±18	2.4±0.2
J17	Page	173±12	31.3±1.2	195±12	321±16	516±20	2.7±0.2
A4	USF4	173±12	36.9±1.4	200±12	313±11	514±16	2.6±0.2

For TLD's average value from top and bottom readings of both types used

More complete SI 2 data – contribution of Nakahiro Yasuda

Conclusions

- The results of two intercomparisons onboard ISS during the same period - the daily values of total dose equivalent varying from 400 to 700 μSv , quality factors between 2.0 and 2.9. i.e. in general agreement with those at other missions and studies onboard ISS
- Important variations of all quantities determined observed for SPD test, (3.5 years stockage before the exposure?); the values obtained for SI2 intercomparison much more consistent (variations of total H less than $\pm 12\%$)
- The values recalculated for 1 year exposure are largely inferior to the annual Russian annual effective dose limit 500 mSv
- Further studies needed to get the data set on area variation of exposure level inside the ISS more complete and reliable.

Acknowledgements

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