

# Radiation Measurements with passive detectors during recent Shuttle flights

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# Outline

- Motivation
- TL measurements (STS-119)
- CR-39 measurements (STS-126)
- Summary
- Outlook

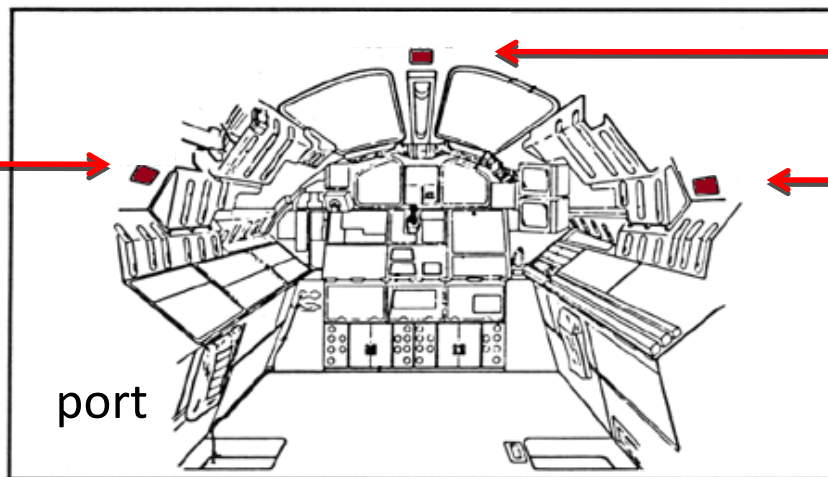
# Motivation

- What?  
Monitoring radiation environment on ISS, Shuttle as well as crew personnel
- Why?  
ALARA in Low Earth Orbit
- How?  
Passive Dosimeters

# Passive Radiation Dosimeters

Flight Deck

PRD 6



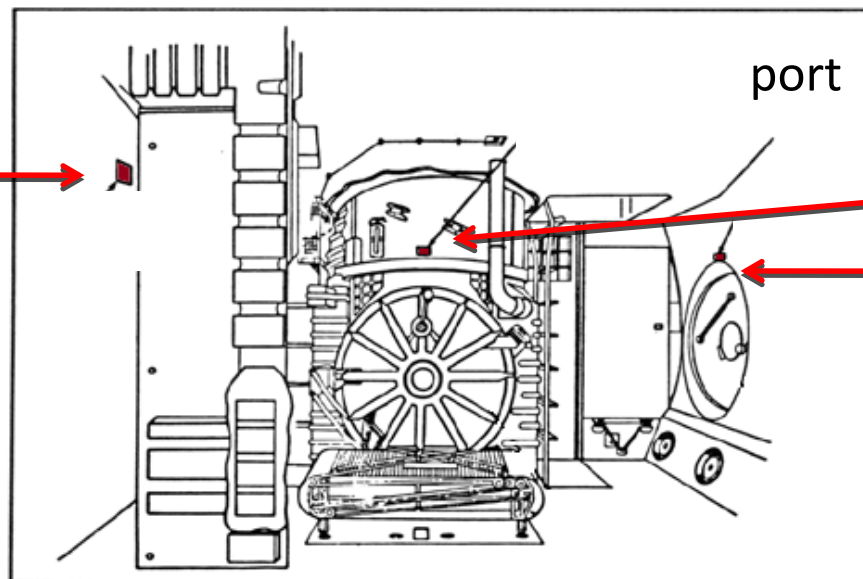
PRD 4

PRD 5

port

Mid Deck

PRD 2



port

PRD 1

PRD 3

# STS-119 – Thermoluminescence

## Shuttle Transportation System (STS) 119

Discovery

Duration: 12.8 days

Inclination: 51.6°

Altitude: 365 km



# STS-119 – Properties

## Number of detectors:

84x TLD 100

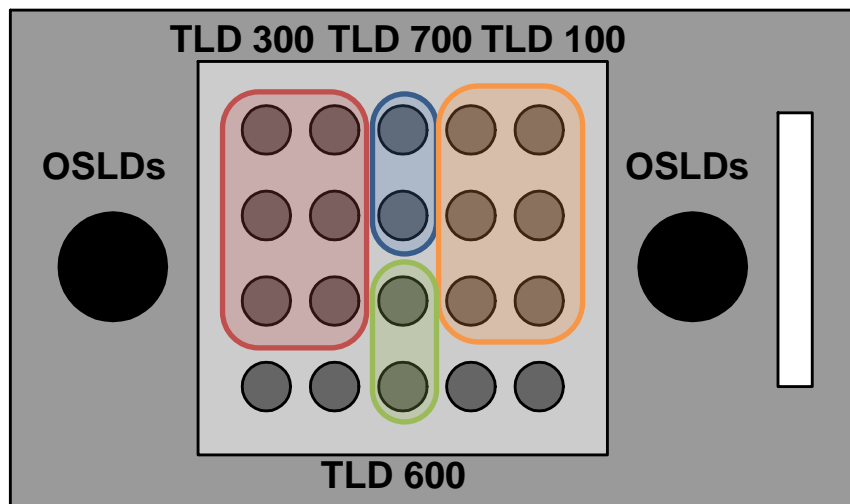
84x TLD 300

36x TLD 600

36x TLD 700

84x OSLDs

28x CR-39 plates



# STS-119 – TL Procedures

	TLD 100 (LiF:Mg,Ti)	TLD 300 (CaF <sub>2</sub> :Tm)
<b>Pre exposure annealing</b>	1 h 400°C, slow cool in oven overnight	1 h 400°C, 2 h 100°C, cool at room temperature
<b>Post exposure annealing</b>	30 min 100°C, cool at room temperature	30 min 100°C, cool at room temperature
<b>Measurements</b>		
Preheat	100°C	100°C
Heating rate	6°C/s	6°C/s
Calibration region	160°C – 280°C (main peak)	230°C – 370°C (high temperature peak)
<b>Data analysis</b>	Signal – Dose Conversion (Calibration against known gamma source)	

# STS-119 – TL Procedures

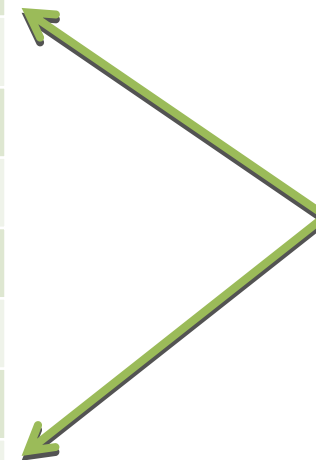
## Data analysis:

- Calibration against known gamma source

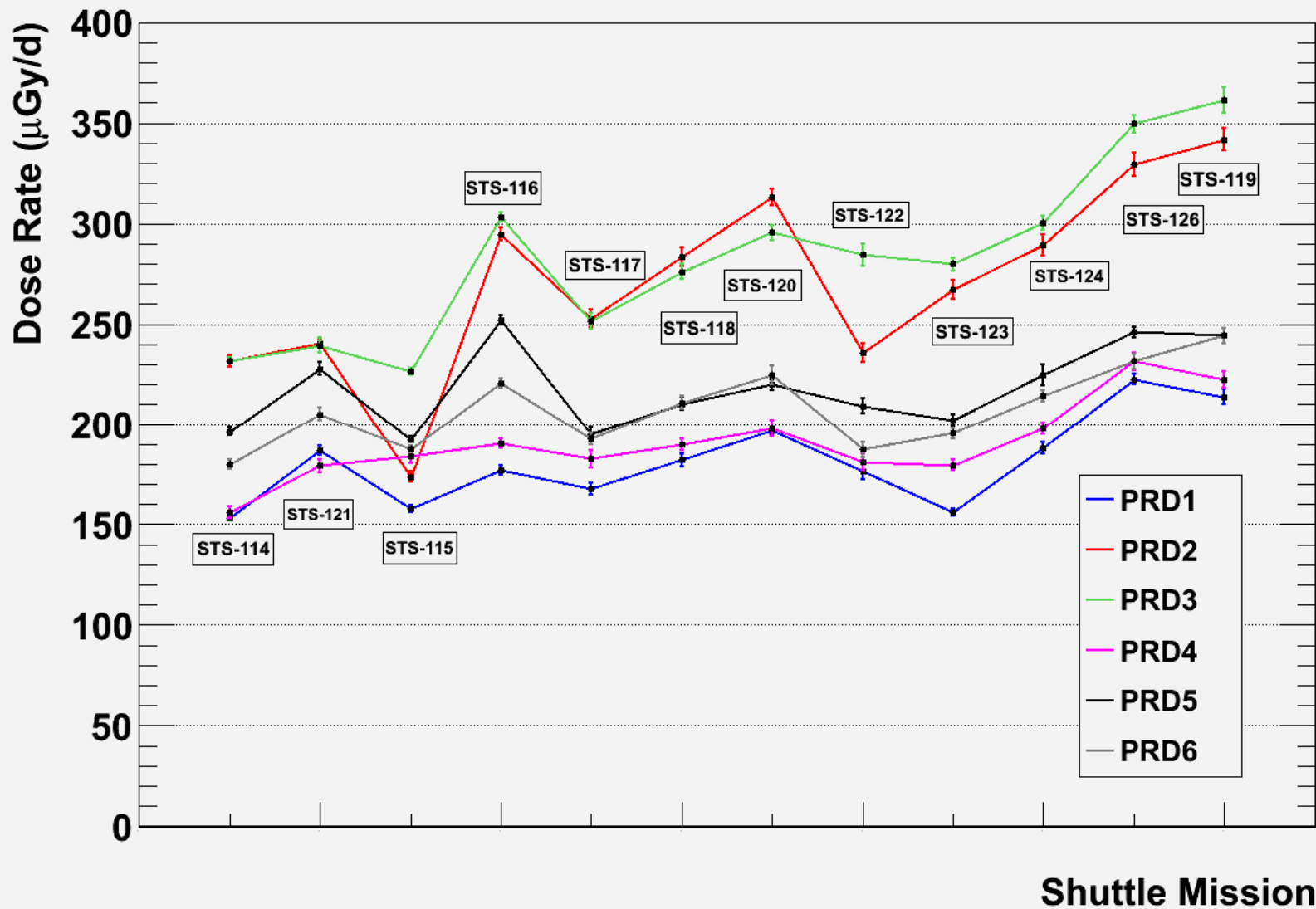
$$\frac{S_{meas}}{D_{meas}} = \frac{S_{\gamma}}{D_{\gamma}} \longrightarrow D_{meas} = \frac{S_{meas} \cdot D_{\gamma}}{S_{\gamma}}$$

# STS-119 – TL results

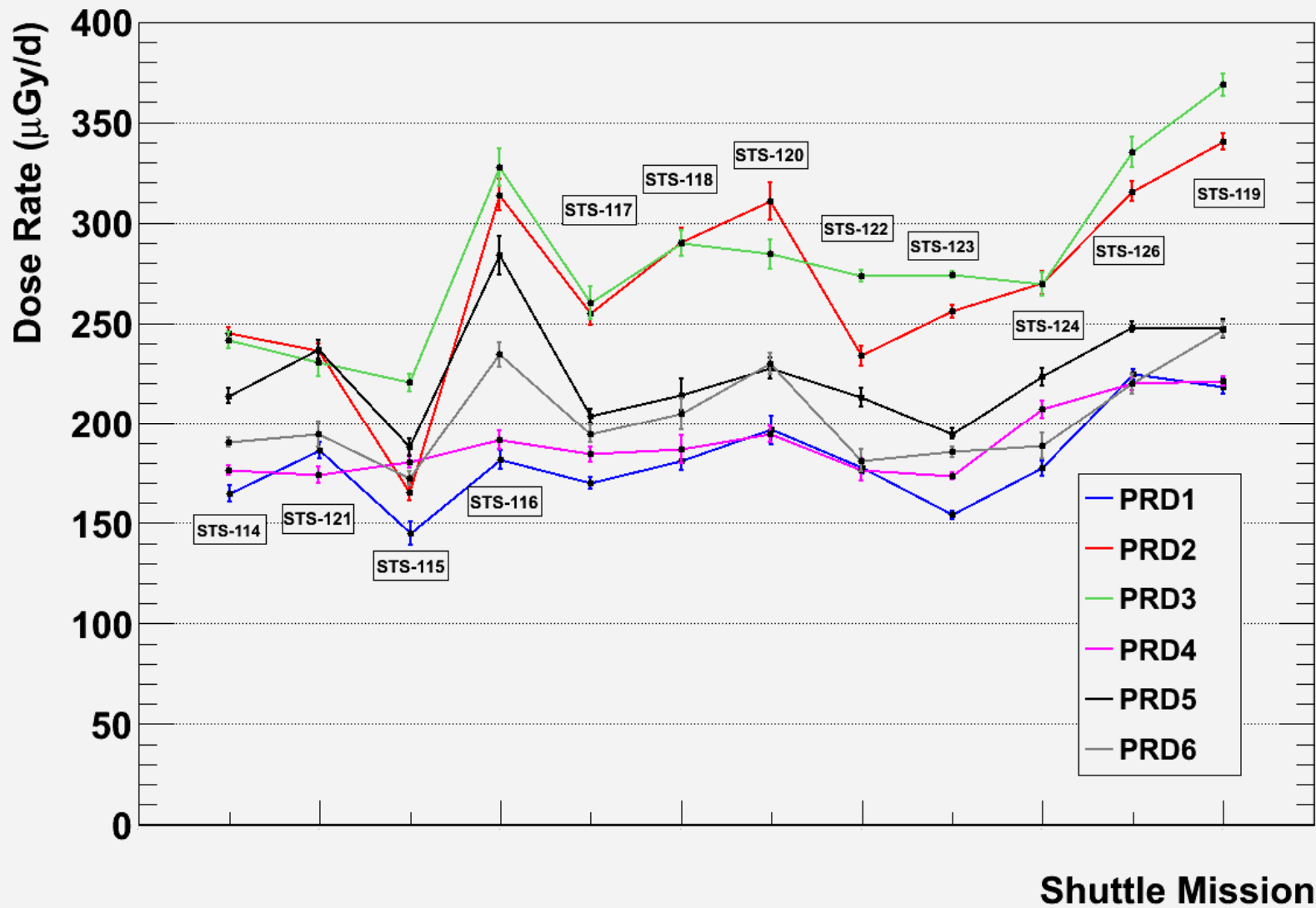
	TLD Type	Dose (mGy)
PRD 1	TLD 100	2.74 ± 0.05
	TLD 300	2.80 ± 0.06
PRD 2	TLD 100	4.38 ± 0.07
	TLD 300	4.36 ± 0.05
PRD 3	TLD 100	4.63 ± 0.08
	TLD 300	4.72 ± 0.07
PRD 4	TLD 100	2.85 ± 0.05
	TLD 300	2.83 ± 0.03
PRD 5	TLD 100	3.13 ± 0.05
	TLD 300	3.17 ± 0.06
PRD 6	TLD 100	3.13 ± 0.05
	TLD 300	3.16 ± 0.05



# Dose Rate for TLD 100



# Dose Rate for TLD 300



# STS-126 – CR-39

## Shuttle Transportation System (STS) 126

Endeavour

Duration: 15.9 days

Inclination: 51.6°

Altitude: 359.6 km



# STS-126 – Properties

## Number of detectors:

84x TLD 100

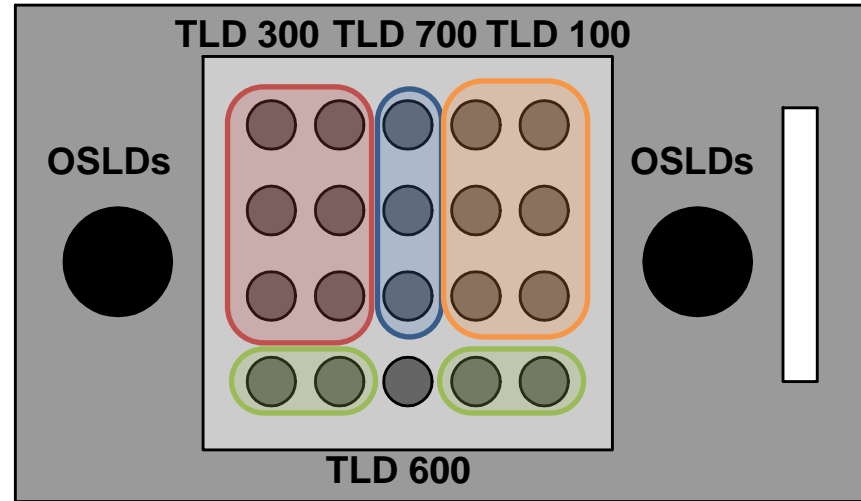
84x TLD 300

56x TLD 600

44x TLD 700

84x OSLDs

28x CR-39 plates



# STS-126 – CR-39 Procedures

	CR-39
<b>Pre exposure preparations</b>	Removal of protective film, Mark on good side
<b>Post exposure etch</b>	38 h, 60°C, NaOH (6.25N) Bulk Etch calculation
<b>Data scan (manual)</b>	major, minor axis
<b>Data analysis</b>	Etch Rate Ratio LET (through calibration) Differential Fluence Absorbed Dose Dose Equivalent Combination of TL/OSL/CR-39

# STS-126 – CR-39 Procedures II

## Data analysis:

- Bulk Etch

$$B_t = \frac{(m_1 - m_2)T_2}{2m_2} \left(1 - \frac{pT_2}{2A}\right)$$

- Etch Rate Ratio

$$S = \sqrt{1 + 4 \left(\frac{a}{2B}\right)^2 / \left(1 - \left(\frac{b}{2B}\right)^2\right)}$$

- LET values via calibration curve

# STS-126 – CR-39 Procedures III

## Data analysis:

- Differential Fluence

$$F = \frac{d^3N}{dAd\Omega dLET} = (2\pi A \cos^2 \delta_{cut})^{-1} \frac{dN}{dLET}$$

- Differential Dose

$$\text{Dose} = 4\pi \times 1.6 \times 10^{-9} \times LET_{\infty} \times F$$

- Integral Dose Equivalent

$$H = \int Q(L) \cdot D_{PNTD}(L) dL$$

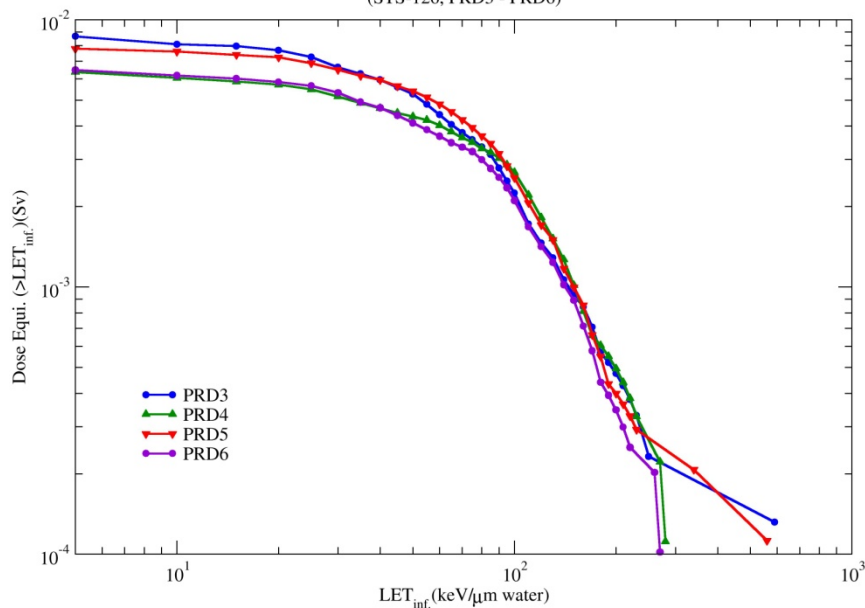
- Average Quality Factor

$$Q = \frac{H}{D}$$

# STS-126 – CR-39 results

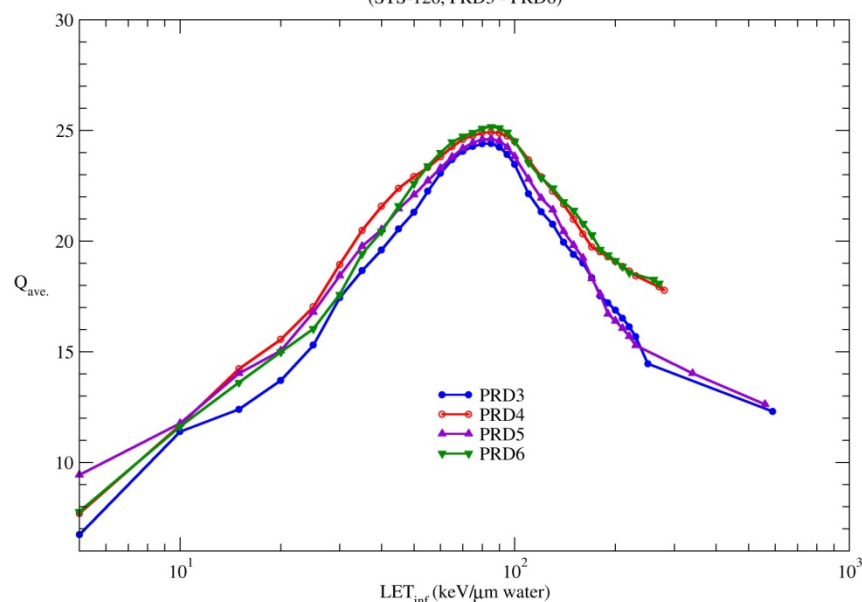
Integral LET Spectrum (Dose Equivalent, ICRP 60)

(STS-126, PRD3 - PRD6)



Quality Factor (ICRP 60)

(STS-126, PRD3 - PRD6)



# STS-126 – CR-39 results

	Dose (mGy) high LET, Q>11	Dose Equivalent (mSv)	Quality Factor
PRD 3	0.71 ± 0.04	8.09 ± 0.48	11.39 ± 0.57
PRD 4	0.52 ± 0.04	6.06 ± 0.50	11.68 ± 0.96
PRD 5	0.65 ± 0.04	7.60 ± 0.43	11.76 ± 0.66
PRD 6	0.53 ± 0.04	6.18 ± 0.45	11.62 ± 0.84



## Data analysis:

- Combination of TLD/OSLD/CR-39 with average detection efficiency

$$\varepsilon_{aver} = \frac{\sum_{L_i=10keV/\mu m}^{LET_{max}} \varepsilon(L_i) D_i(L_i)}{D_{CR-39}^{LET \geq 10keV/\mu m}}$$

# STS-126 – CR-39 results

Location	Type	Measured Dose	Dose Low LET	Dose High LET	Total Dose	Dose Equivalent	Quality Factor
PRD 3	TLD 100	5.54 ± 0.07	5.13 ± 0.07	0.71 ± 0.04	5.84 ± 0.08	13.22 ± 0.49	2.26 ± 0.08
	TLD 300	5.31 ± 0.12	4.70 ± 0.12		5.41 ± 0.13	12.78 ± 0.49	2.36 ± 0.09
	OSLD 300s	5.36 ± 0.07	4.97 ± 0.07		5.68 ± 0.08	13.05 ± 0.49	2.30 ± 0.09
PRD 4	TLD 100	3.67 ± 0.07	3.46 ± 0.07	0.52 ± 0.04	3.98 ± 0.08	9.52 ± 0.50	2.39 ± 0.13
	TLD 300	3.48 ± 0.05	3.03 ± 0.05		3.55 ± 0.06	9.09 ± 0.50	2.56 ± 0.14
	OSLD 300s	3.53 ± 0.06	3.24 ± 0.06		3.76 ± 0.07	9.30 ± 0.50	2.47 ± 0.13
PRD 5	TLD 100	3.90 ± 0.04	3.53 ± 0.04	0.65 ± 0.04	4.18 ± 0.05	11.13 ± 0.43	2.67 ± 0.10
	TLD 300	3.93 ± 0.04	3.37 ± 0.04		4.02 ± 0.05	10.98 ± 0.43	2.73 ± 0.11
	OSLD 300s	3.78 ± 0.04	3.42 ± 0.04		4.07 ± 0.05	11.02 ± 0.43	2.71 ± 0.11
PRD 6	TLD 100	3.67 ± 0.06	3.36 ± 0.06	0.53 ± 0.04	3.90 ± 0.07	9.55 ± 0.45	2.45 ± 0.12
	TLD 300	3.48 ± 0.08	3.02 ± 0.08		3.55 ± 0.09	9.20 ± 0.46	2.59 ± 0.13
	OSLD 300s	3.45 ± 0.05	3.23 ± 0.07		3.68 ± 0.06	9.33 ± 0.45	2.53 ± 0.12

Dose in mGy; Dose Equivalent in mSv



# Summary

- TL measurements for STS-119 (PRDs)  
CR-39 measurements for STS-126 (PRD3-PRD6)
- Variation of dose values at different locations due to shielding
- Area measurements comparable to previous missions for TL and CR-39 data

# Outlook

- Complete CR-39 training
- Training in OSL work
- Training for use of gamma-source

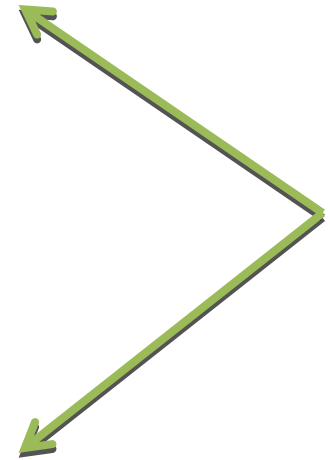


# Thank you!

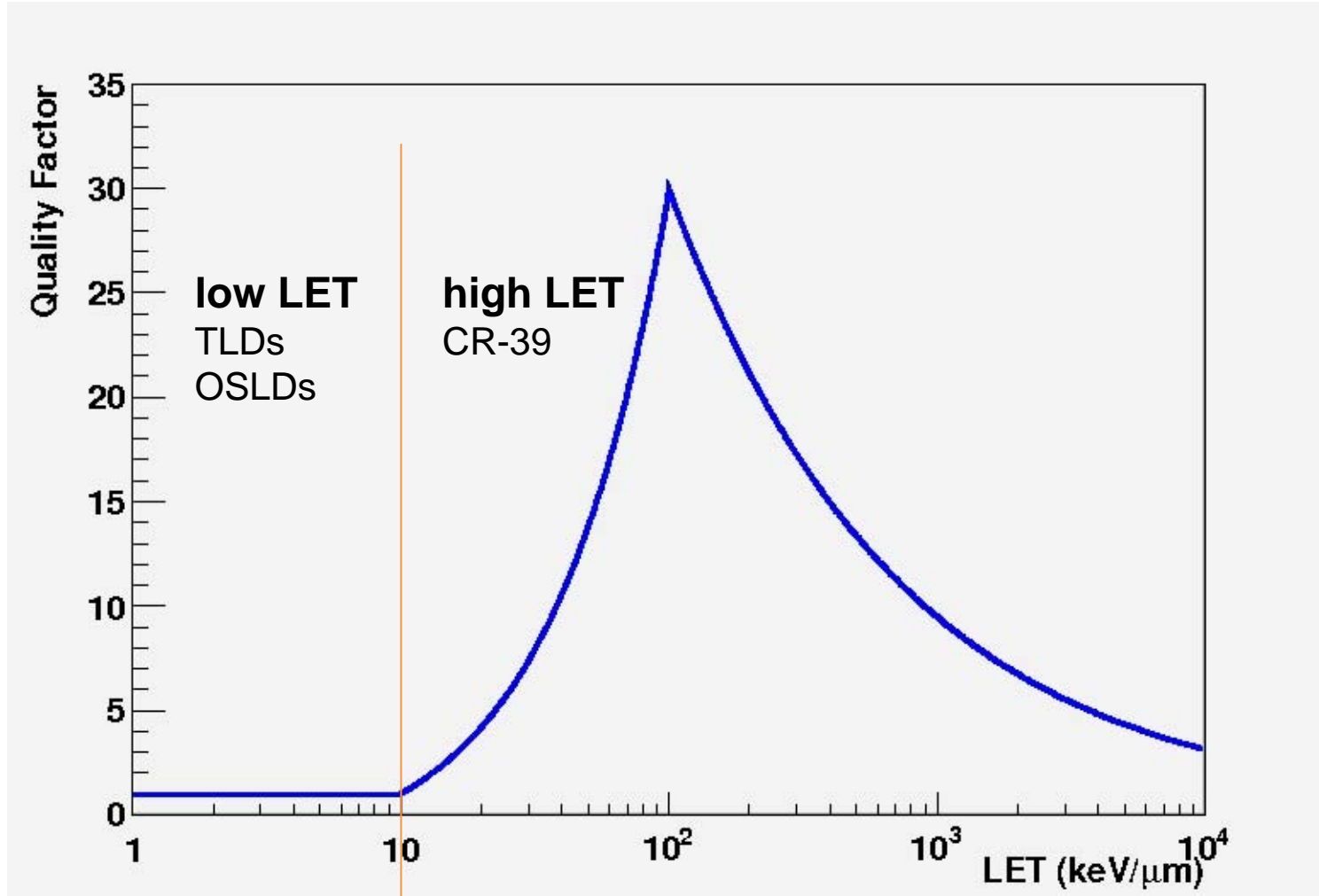


# STS 119 – Thermoluminescence

	TLD Type	Dose (mGy)	Ratio (600/700)
PRD 1	TLD 600	2.86 ± 0.19	1.05
	TLD 700	2.73 ± 0.09	
PRD 2	TLD 600	4.65 ± 0.13	1.02
	TLD 700	4.55 ± 0.13	
PRD 3	TLD 600	4.76 ± 0.26	1.01
	TLD 700	4.71 ± 0.16	
PRD 4	TLD 600	2.95 ± 0.08	1.04
	TLD 700	2.84 ± 0.17	
PRD 5	TLD 600	3.35 ± 0.11	1.00
	TLD 700	3.33 ± 0.07	
PRD 6	TLD 600	3.08 ± 0.09	0.97
	TLD 700	3.16 ± 0.07	



# ICRP 60



# Shuttle Flights

STS	Altitude /km	Inclination /°	Duration /d	Launch	Landing
114	360.9	51.6	13.9	07/26/05	08/09/05
121	330.4	51.6	12.8	07/04/06	07/17/06
115	344.1	51.6	11.8	09/09/06	09/21/06
116	338.8	51.6	12.9	12/10/06	12/22/06
117	327.6	51.6	13.8	06/08/07	06/22/07
118	344.6	51.6	12.7	08/08/07	08/21/07
120	343.2	51.6	15.1	10/23/07	11/07/07
122	328.6	51.6	12.8	02/07/08	02/20/08
123	335.8	51.6	15.8	03/11/08	03/27/08
124	343.4	51.6	13.8	05/31/08	06/14/08
126	359.6	51.6	15.9	11/15/08	11/30/08
119	345.6	51.6	12.8	03/15/09	03/28/09

# STS-126 – CR-39 Procedures IV

## Data analysis:

- Combination of TLD/OSLD/CR-39  
average detection efficiency

$$\varepsilon_{aver} = \frac{\sum_{L_i=10keV/\mu m}^{LET_{max}} \varepsilon(L_i) D_i(L_i)}{D_{LET \geq 10keV/\mu m}^{CR-39}}$$

$$D_{total} = D(TLD, OSLD) + (1 - \varepsilon_{aver}) D(CR - 39)$$

$$H_{total} = H(TLD, OSLD) + (1 - \varepsilon_{aver}) H(CR - 39)$$

$$Q = H_{total} / D_{total}$$