Recent Radiation Monitoring Results: Expedition 10, 11 and STS-114

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WRMISS 10

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NASA

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9/7/05

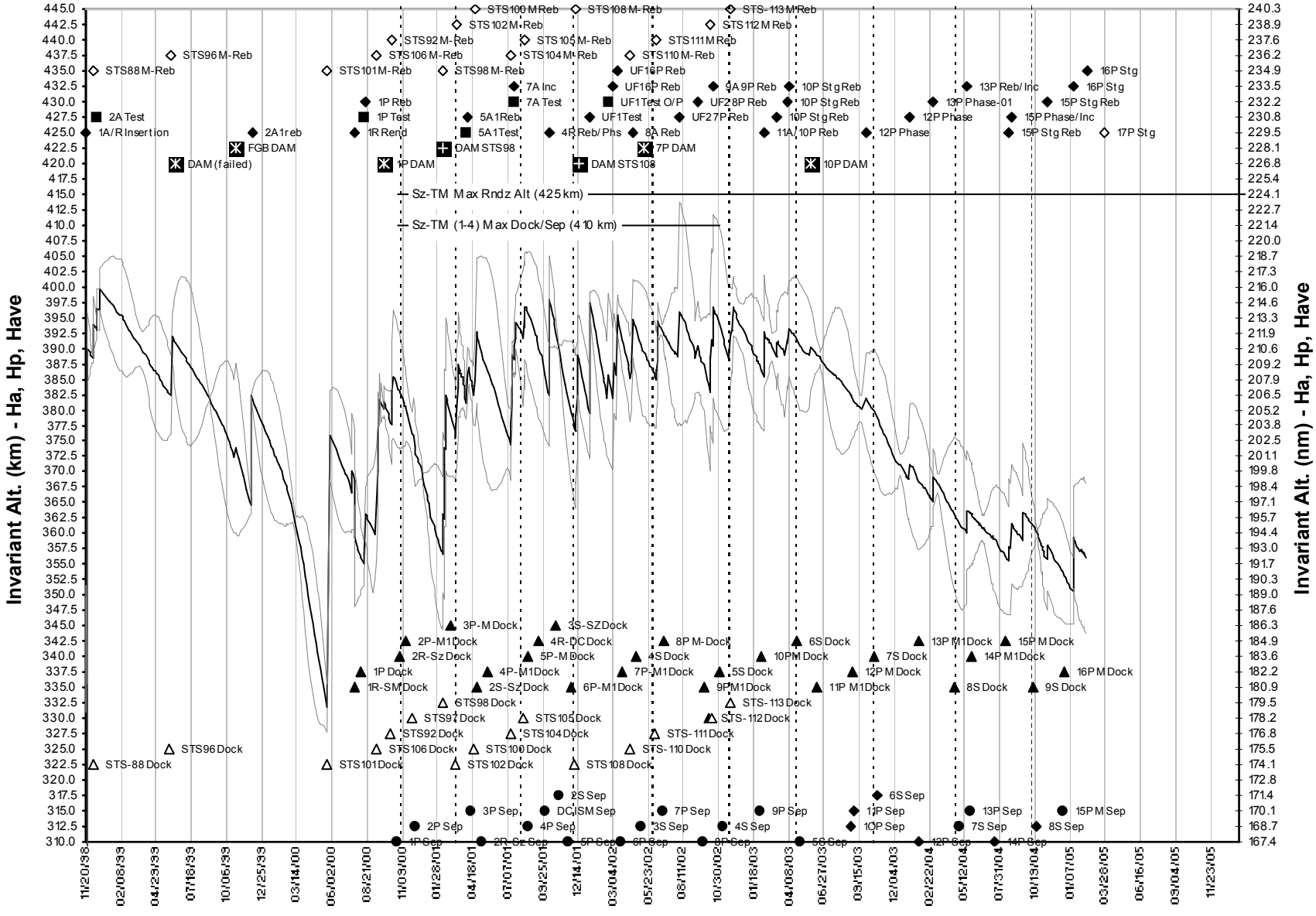
Mission Timeline

Expedition	Status	Launch (GMT)	Landing (GMT)	Duration	Crew
ISS-9	Flown	19-Apr-2004 03:19:00	24-Oct-2004 12:36:00	188 days 9 hr. 17min.	Gennady Padalka, Michael Fincke
ISS-10	Flown	14-Oct-2004 03:06:00	24-Apr-2005 22:08:00	192 days 19 hr. 2min.	Leroy Chiao, Salizhan Sharipov
ISS-11	In Progress	15-Apr-2005 00:46:25	Estimated: 10-Oct-2005	177 days 23 hr. 13min.	Sergei Krikalev, John Phillips

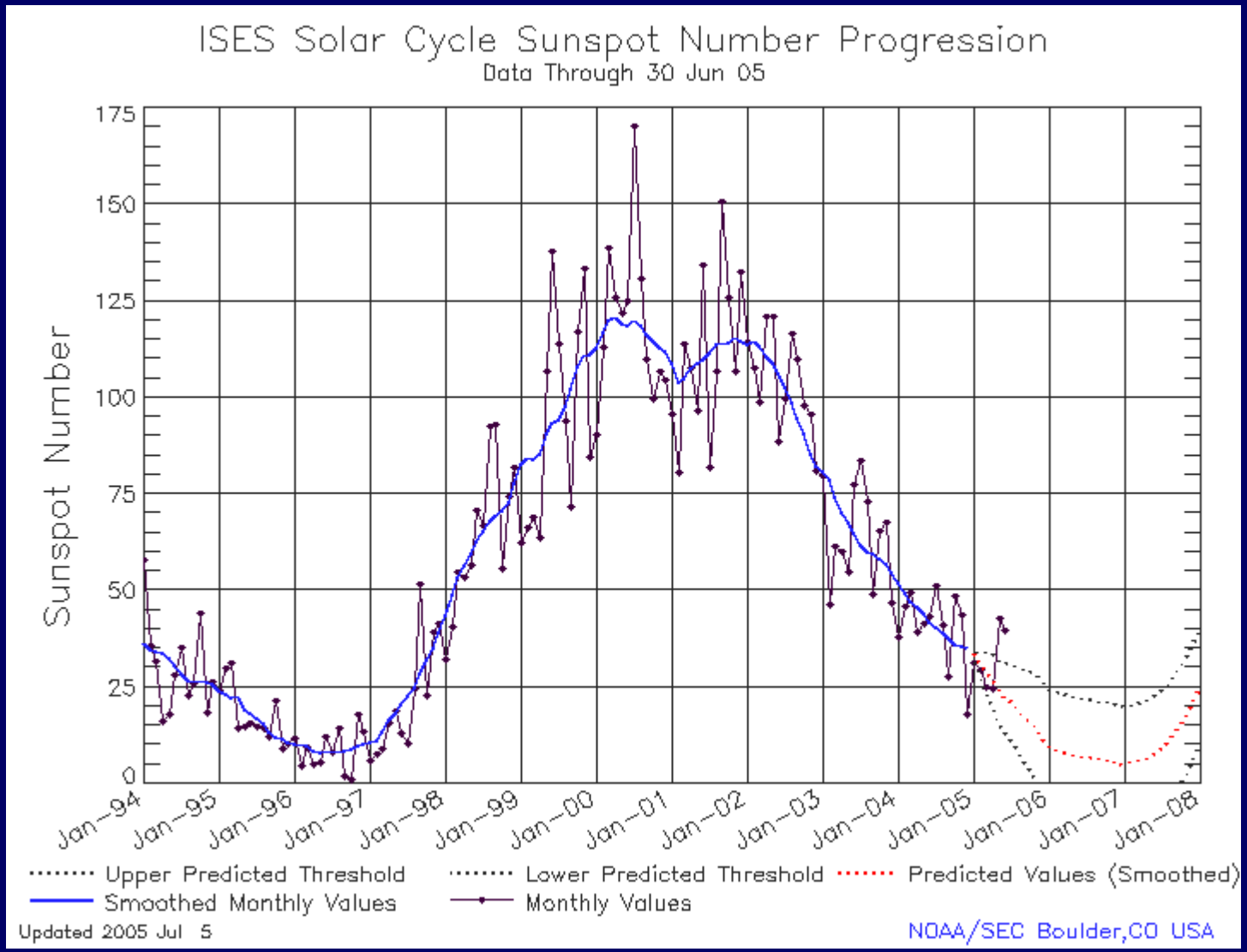
Mission (Increment)	Status	Launch Date (GMT)	Landing Date (GMT)	Duration (hours)	Inclination (°)	# Crew	# Intl. Crew	EVA's	Vehicle
STS-114 (LF1)	Flown	26-Jul-2005 14:39:01	09-Aug-2005 12:11:00	13 days 21 hr. 31min.	51.6	7	1	3	Discovery

International Space Station As Flown Altitude Profile

(Based on MCC-M/USSP Tracked SV Data)



Solar Cycle Progression



SRAG Operational Radiation Measurements

Area monitoring devices

- Passive detectors: Thermoluminescence Dosimeters (TLD), Optically Stimulated Luminescence detectors (OSLDs) and Plastic Nuclear Track Detectors (PNTD)
- Active detectors: Tissue Equivalent Proportional Counters (TEPC) and Solid-State (Si) Detectors: IV-CPDS, EV-CPDS

Personal dosimetry- Each crewmember carries a dosimeter for the duration of their mission.

- TLDs: LiF:Mg,Ti; CaF_2:Tm
- PNTD CR-39 (USF-4, 600 μm)
- OSLDs: Luxel, "dots" and roll

  22-24 detectors in Lexan holder at a depth of 0.18 g/cm^2

Space radiation dosimetry

- What we want: Dose equivalent:

$$H = \sum_i H_i = \sum_i D_i \times Q(L_i)$$

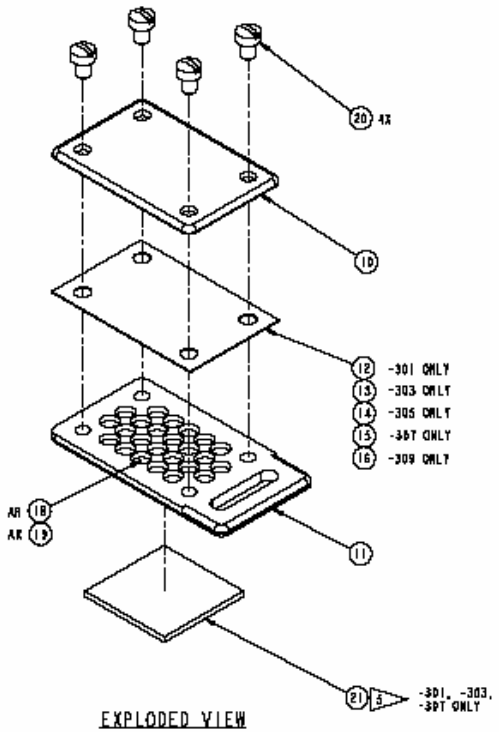
- NCRP 142, 2002 Recommendation 11, Equation 6.1:

$$H = QD_{OSLD/TLD} + \int Q(L)\, D_{PNTD}(L)\, dL$$

LET $\leq$ 10 keV/μm; Q = 1

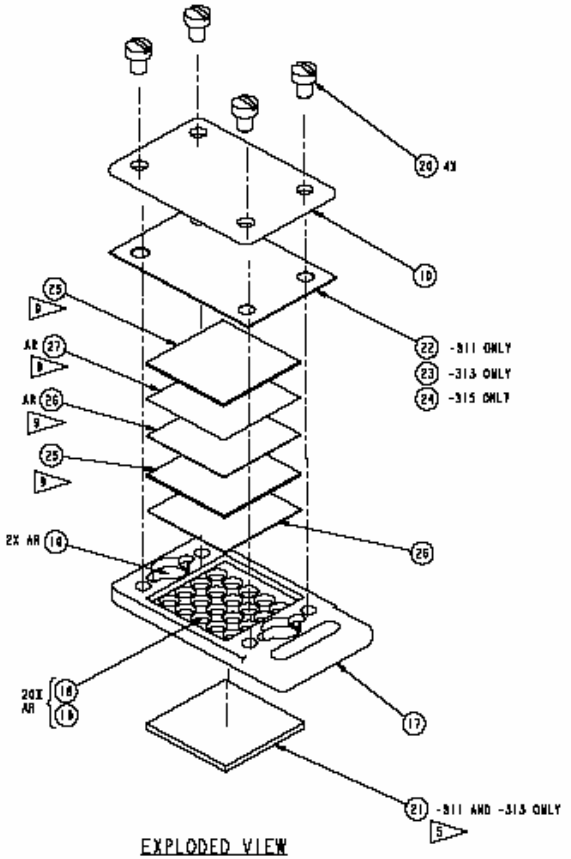
LET $\geq$ 10 keV/μm; Q = Q(L)

Schematic of Passive Dosimeters



EXPLODED VIEW

-301
-303
-305
-307
-309



EXPLODED VIEW

-311
-313
-315

New NASA-SRAG Passive Radiation Detector used for STS-114 and Expedition 12

- TLD-100 (8 samples)
- TLD-300 (6 samples)
- TLD-600 (2 samples)
- TLD-700 (2 samples)
- OSLD/Luxel (2 samples; 6 samples future flights)
- CR-39 (2 samples)

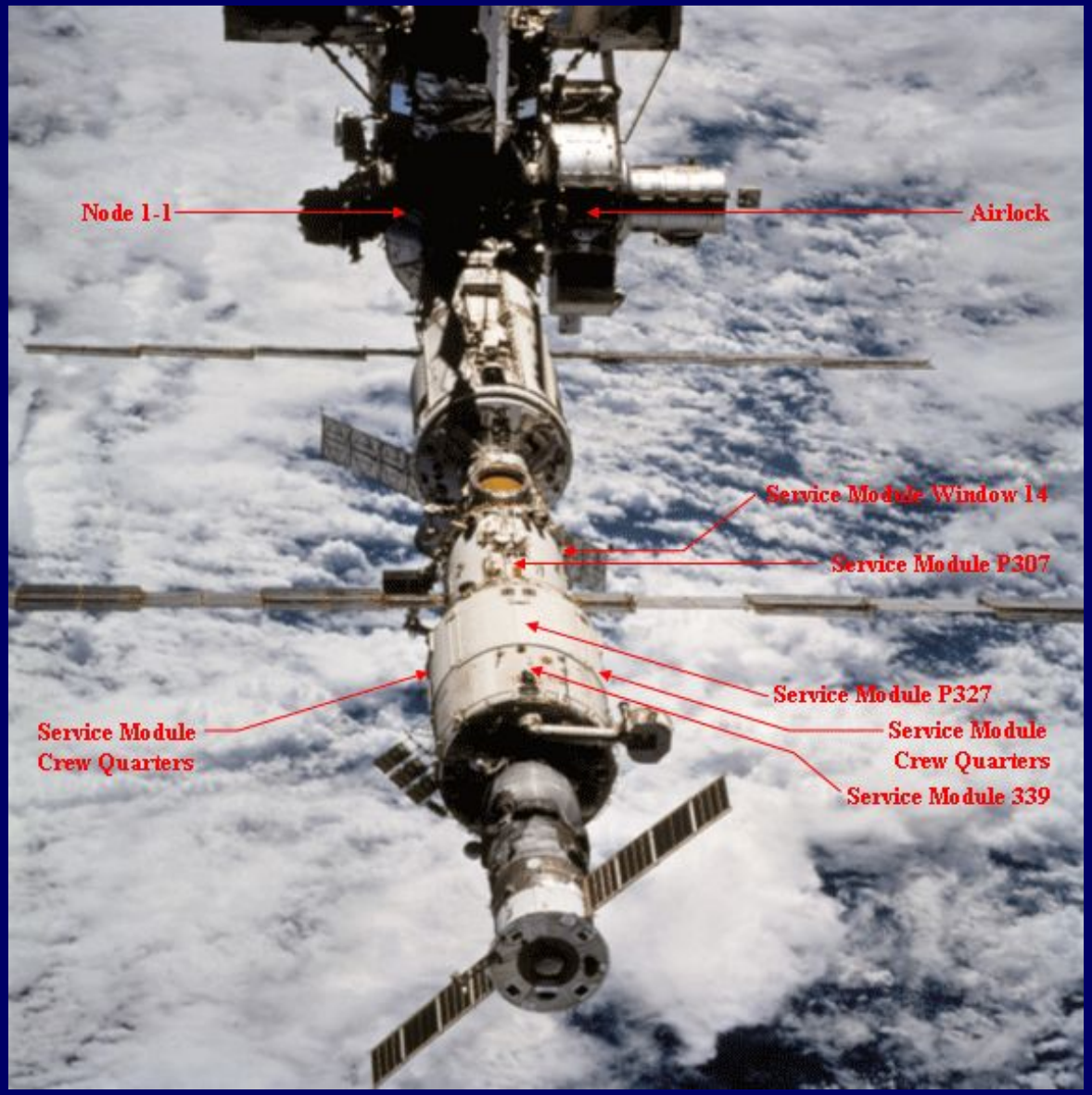
Detector Stack

Lexan Cover: 0.15 cm
Label (White Paper)
CR-39 (**1** Sheet, Bare) 600 μm
Polycarbonate Film (**1** Sheet)
CR-39 (**1** Sheet, Bare) 600 μm
Polycarbonate Film (**2** Sheets)

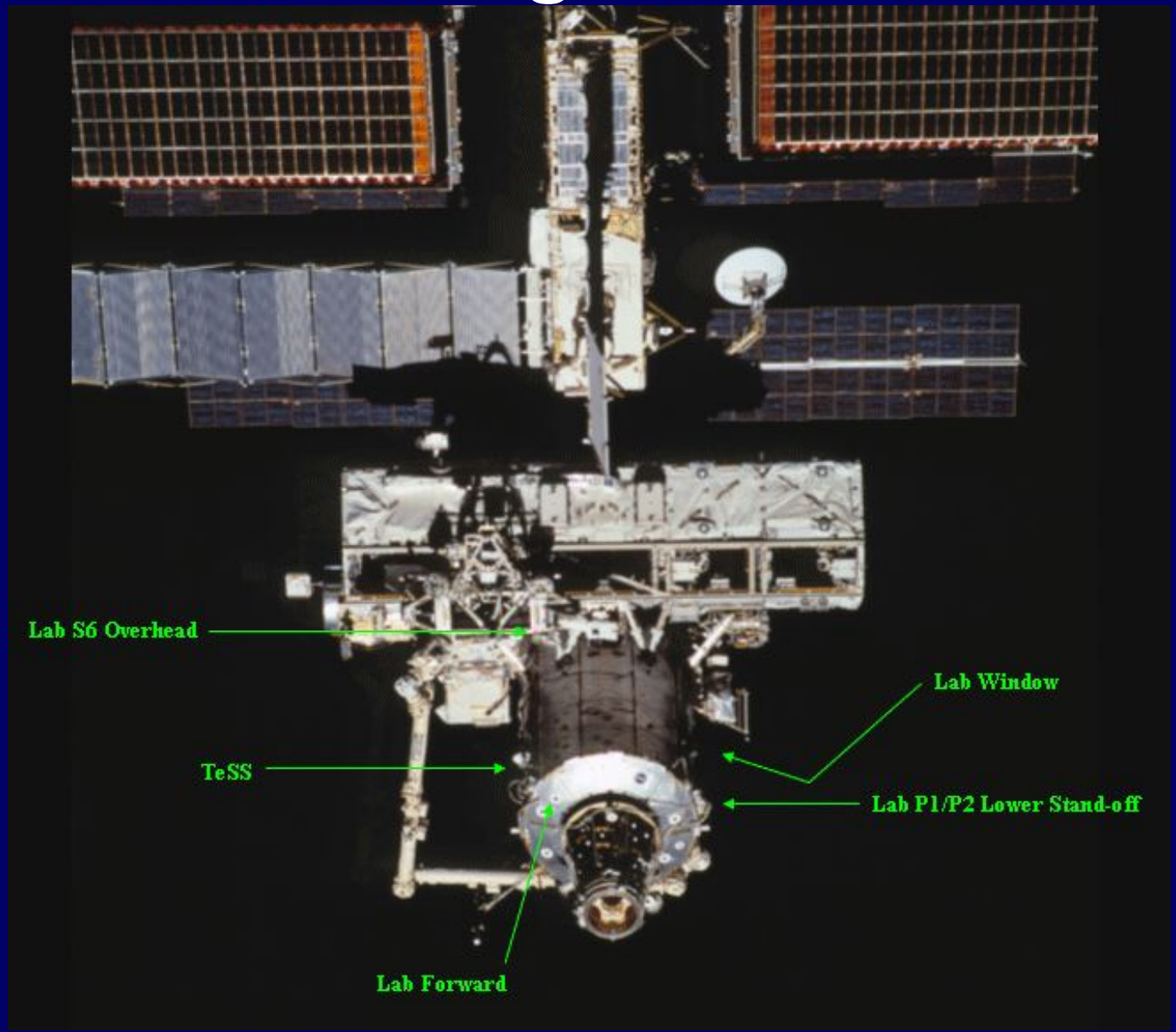
TLDs/OSLD in Lexan Holder: 0.45 cm

Service Module Monitoring Locations

US Destiny Lab to Zvezda SM = 44.5 meters



US LAB Monitoring Locations



Overall View of Monitoring Locations

Node Dosimeter Location 2

SM-P327 (R16) Location

ISS008E09109

ISS008E09117

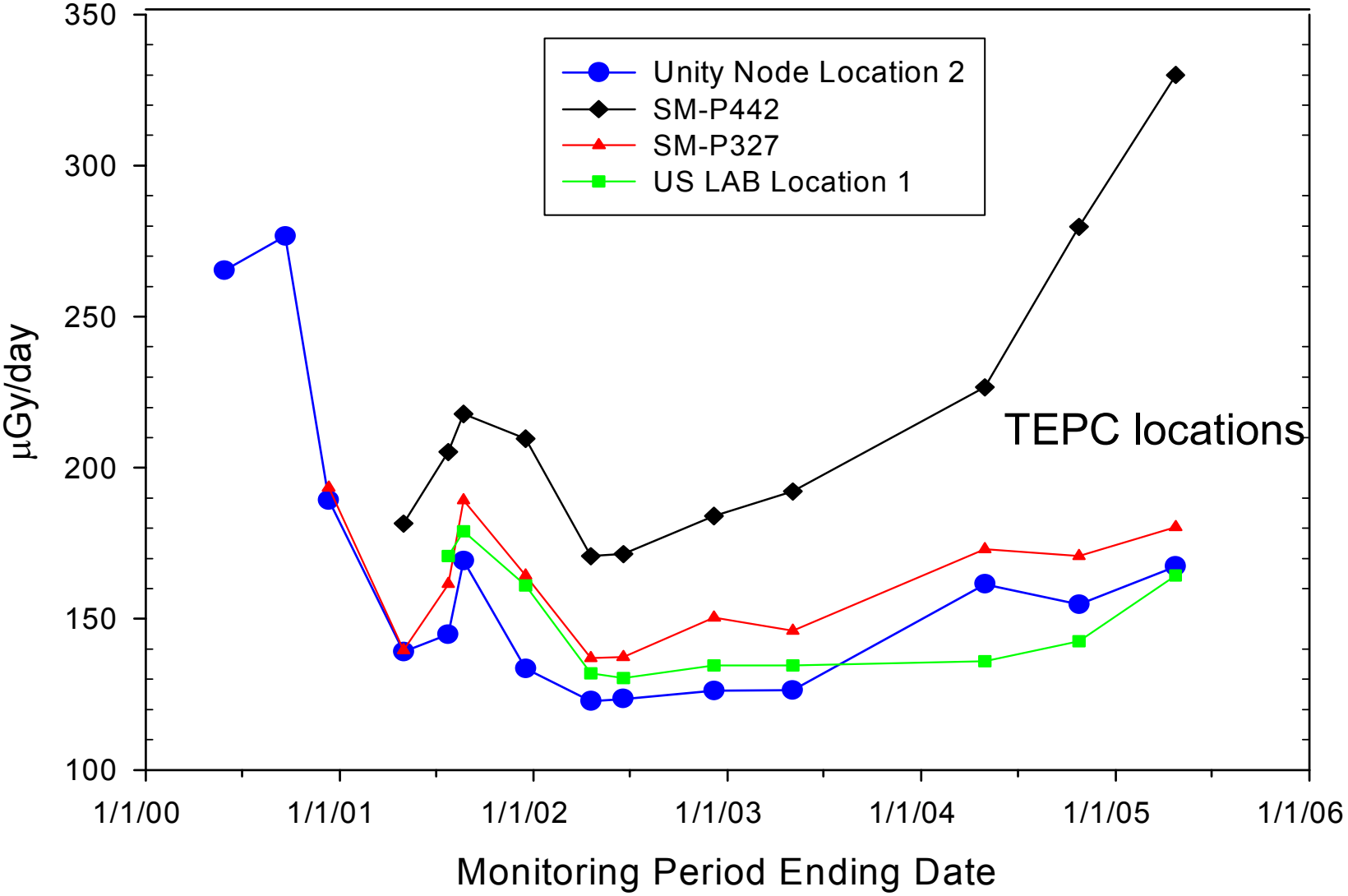
ISS RAM monitoring Periods for Expedition 1-10

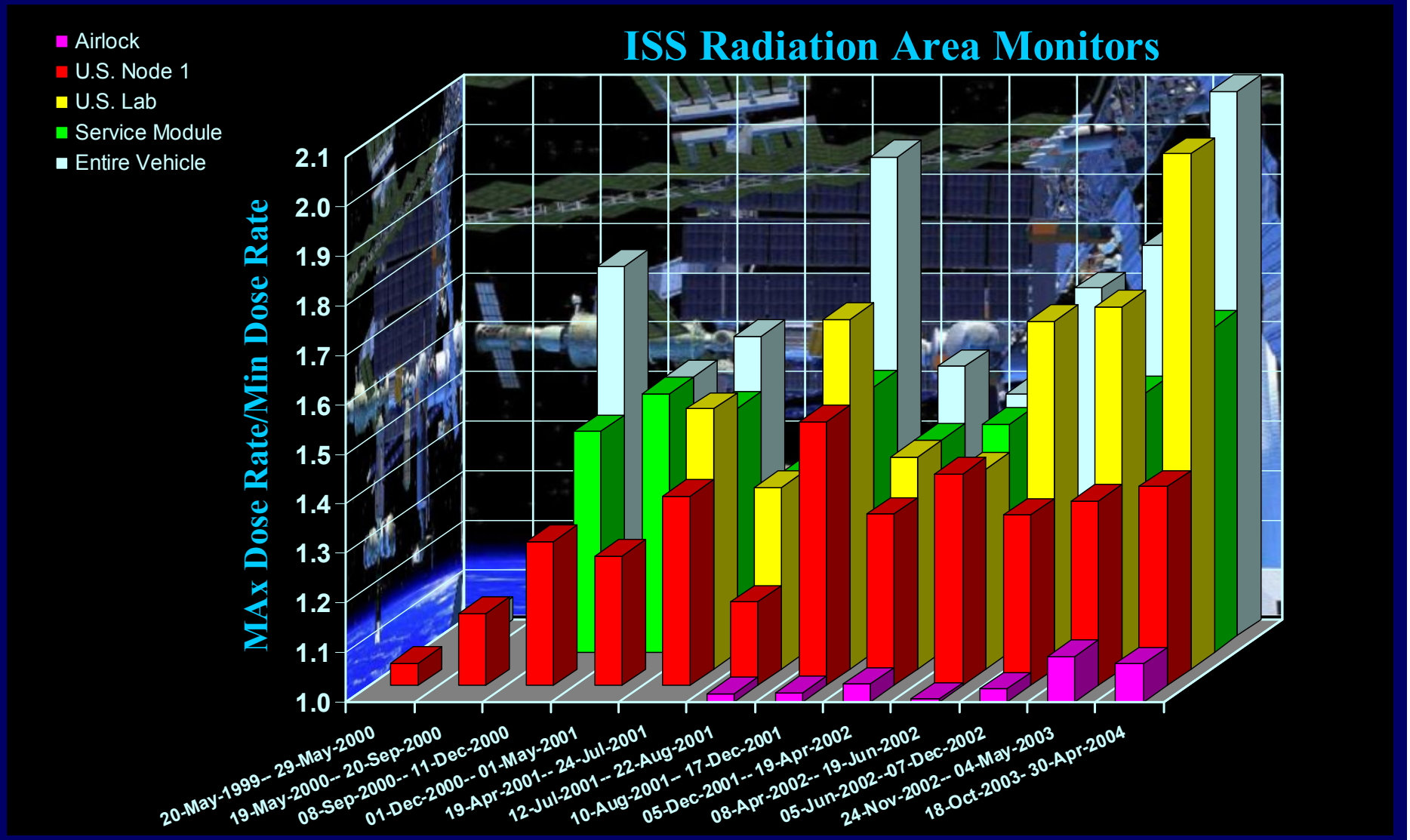
Start Date	End Date	Exposure Duration (days)
5/20/1999	5/29/2000	375
5/19/2000	9/20/2000	124
9/8/2000	12/11/2000	93
12/1/2000	5/1/2001	151
4/19/2001	7/24/2001	96
7/12/2001	8/22/2001	40
8/10/2001	12/17/2001	128
12/5/2001	4/19/2002	134
4/8/2002	6/19/2002	71
6/5/2002	12/7/2002	184
11/24/2002	5/4/2003	160
10/18/2003	4/30/2004	195
4/19/2004	10/24/2004	188
10/14/2004	4/24/2005	192

Passive Monitoring Summary

- Since launch of ISS in 1998 there have been **14** separate passive monitoring periods
- The average length of monitoring periods is **152 days.** **~2100 days of continuous monitoring.**
- **There are 17 permanent monitoring locations covering 30 meters of habitable volume**
  - **Monitoring locations are only separated by a few meters**

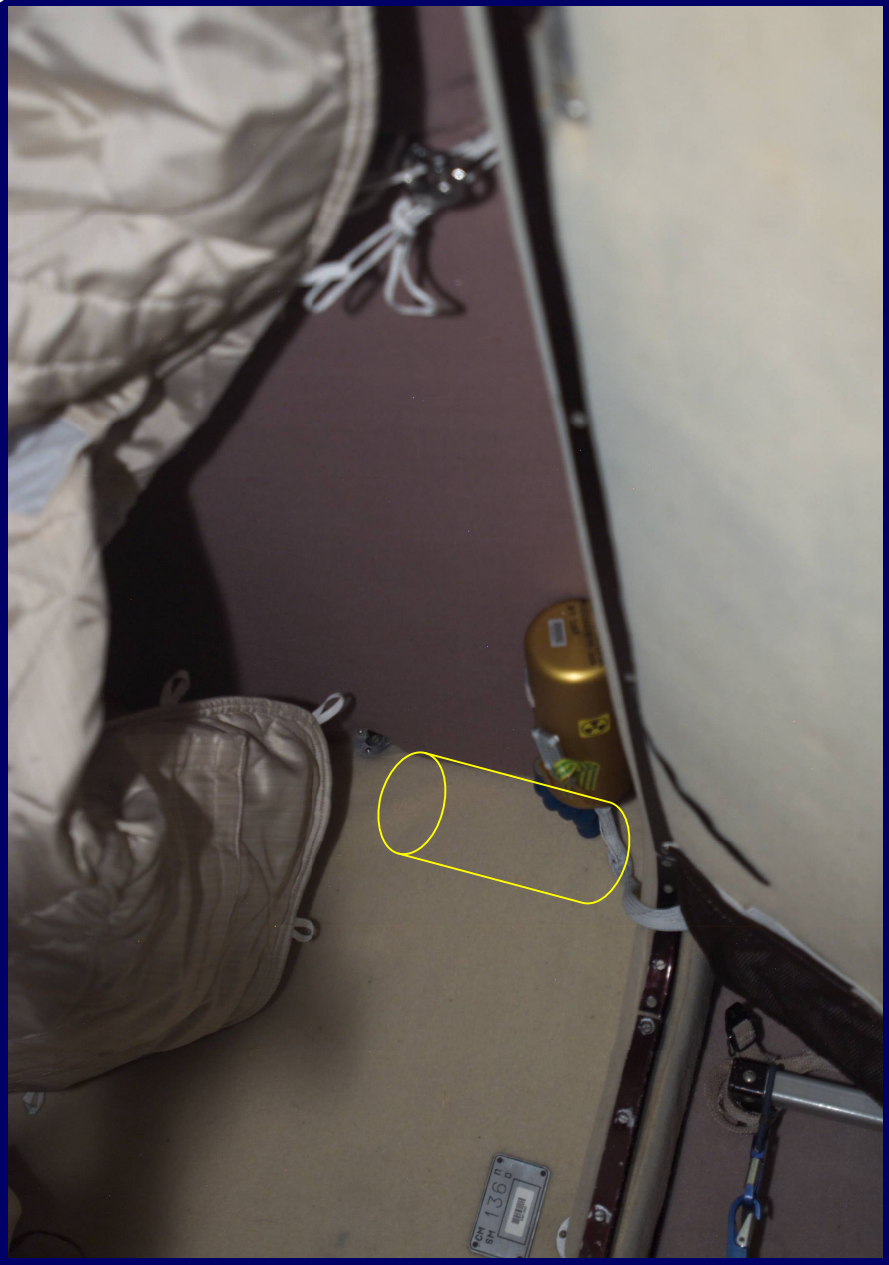
ISS Dose Rate Summary: TLD-100

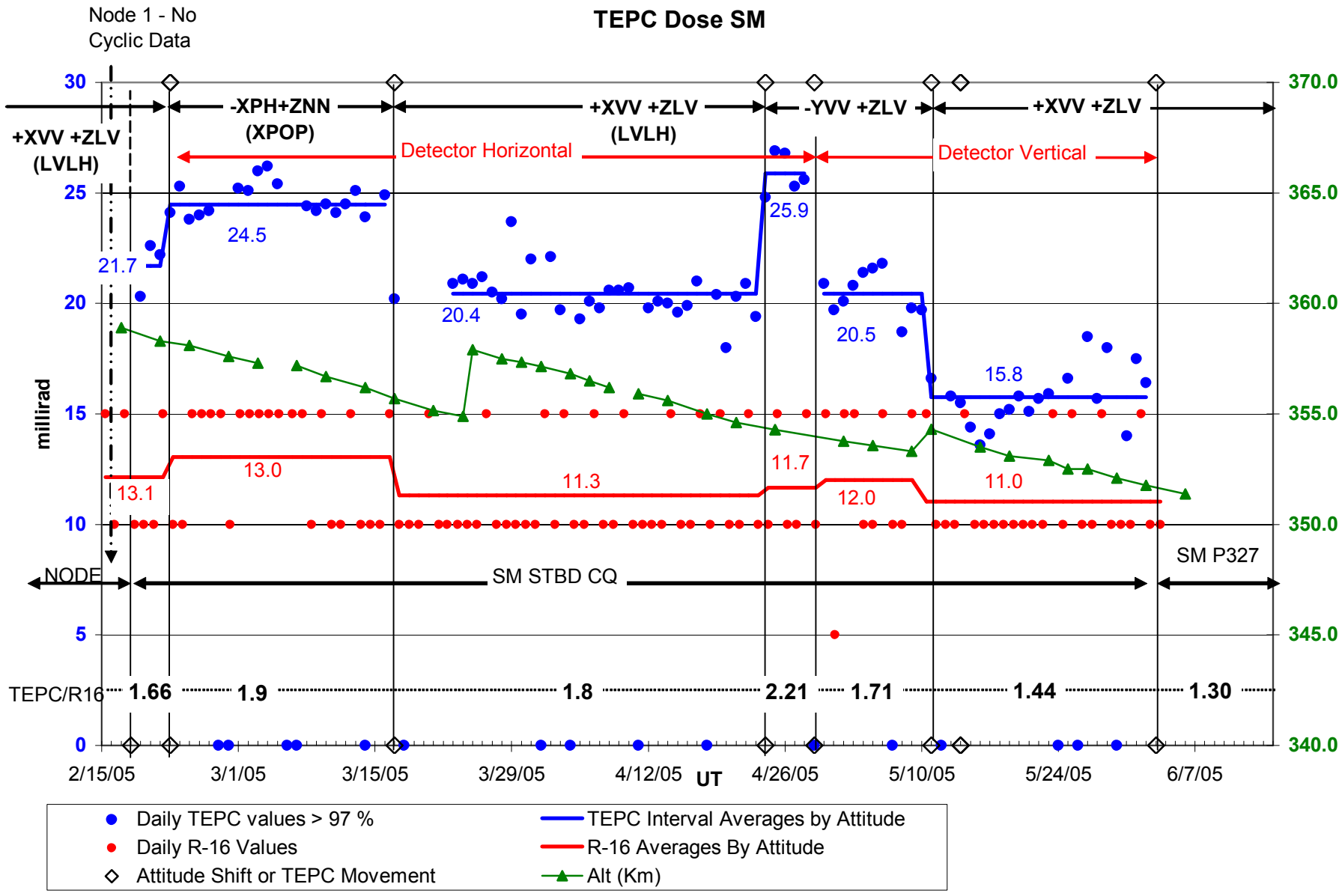


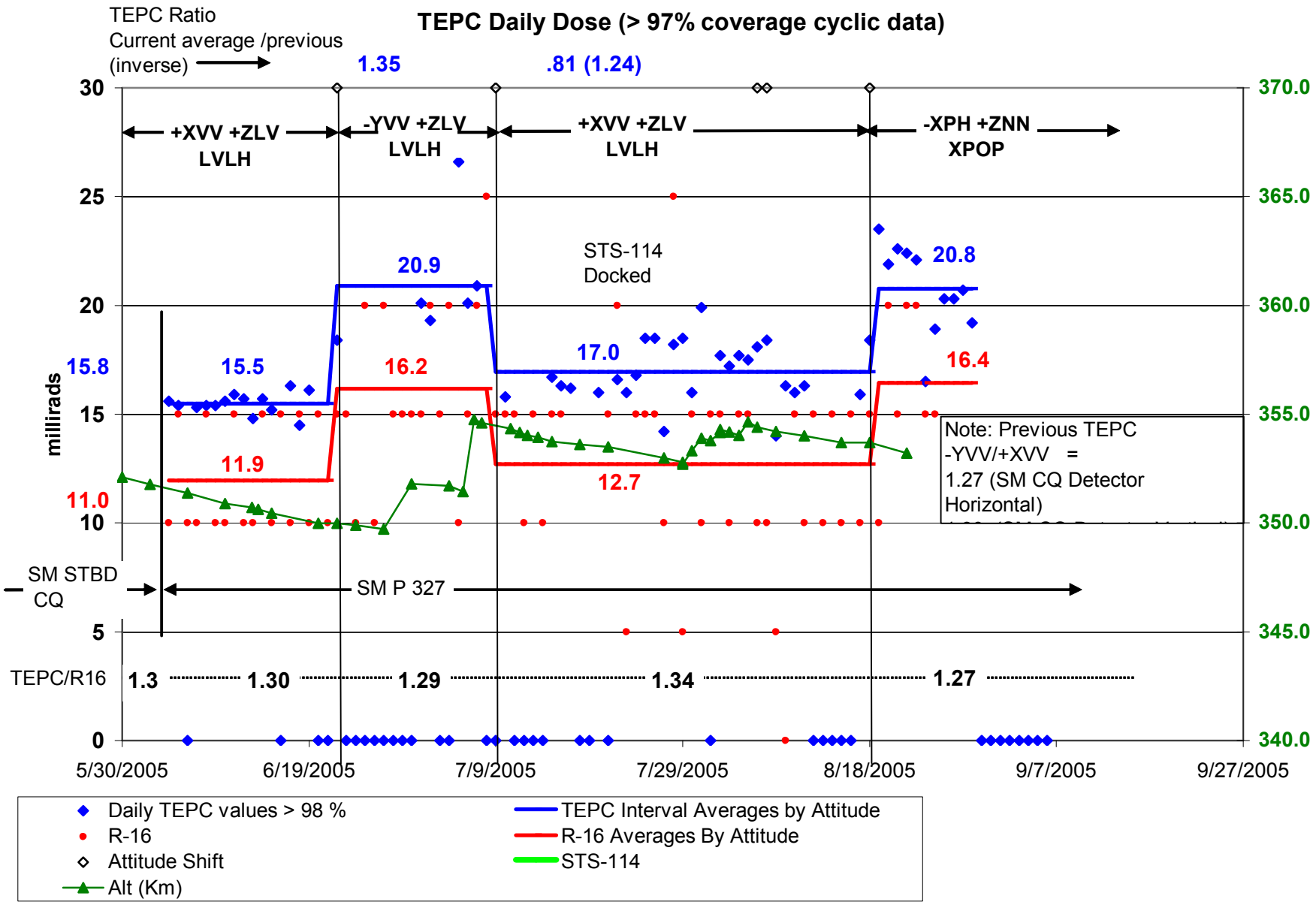

ISS Radiation Area Monitors
Airlock
U.S. Node 1
U.S. Lab
Service Module
Entire Vehicle
MAx Dose Rate/Min Dose Rate
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
20-May-1999-- 29-May-2000
19-May-2000-- 20-Sep-2000
08-Sep-2000-- 11-Dec-2000
01-Dec-2000-- 01-May-2001
19-Apr-2001-- 24-Jul-2001
12-Jul-2001-- 22-Aug-2001
10-Aug-2001-- 17-Dec-2001
05-Dec-2001-- 19-Apr-2002
08-Apr-2002-- 19-Jun-2002
05-Jun-2002-07-Dec-2002
24-Nov-2002-- 04-May-2003
18-Oct-2003- 30-Apr-2004

Horizontal Alignment: SMP442

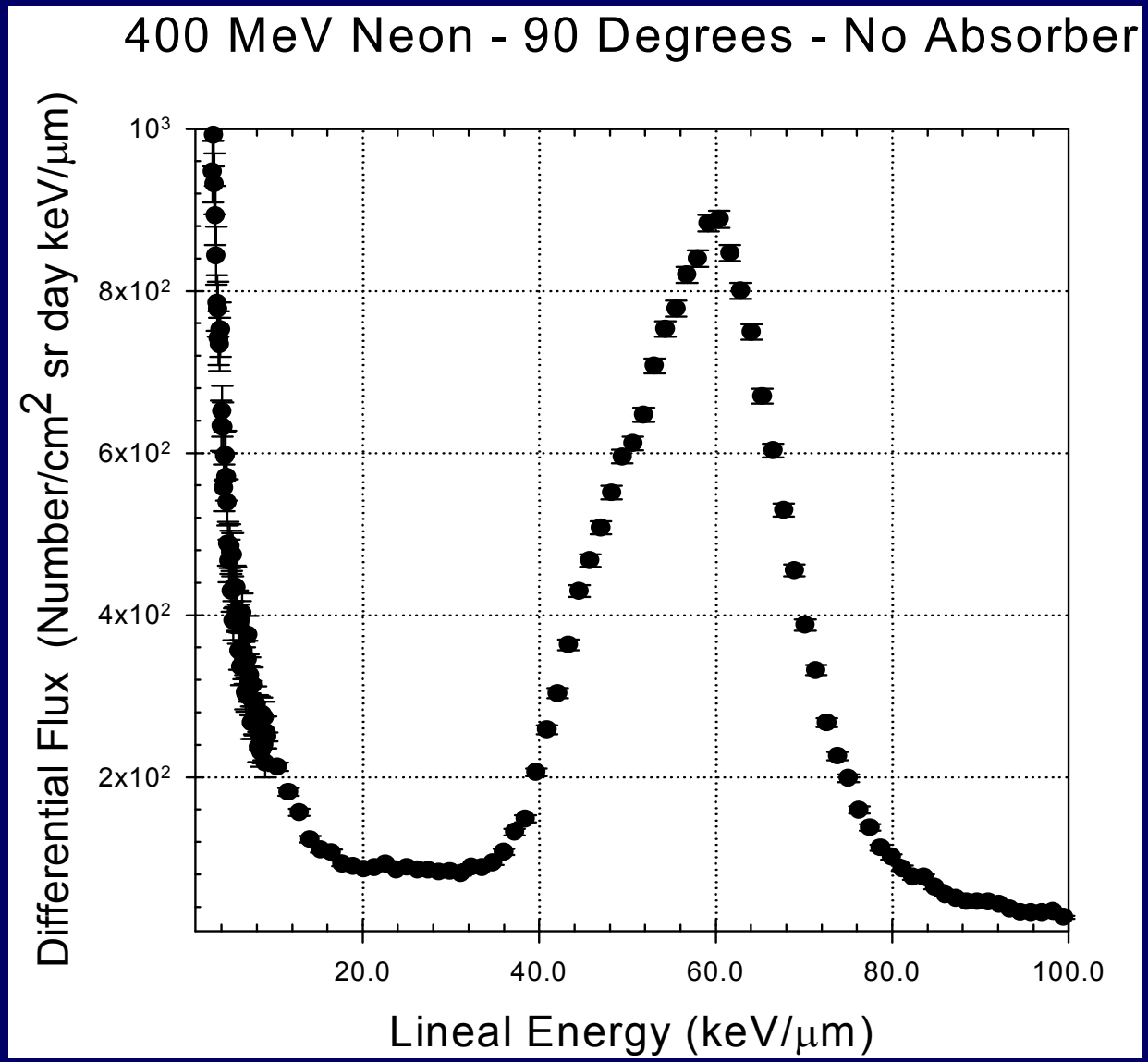
Vertical Alignment: SMP442



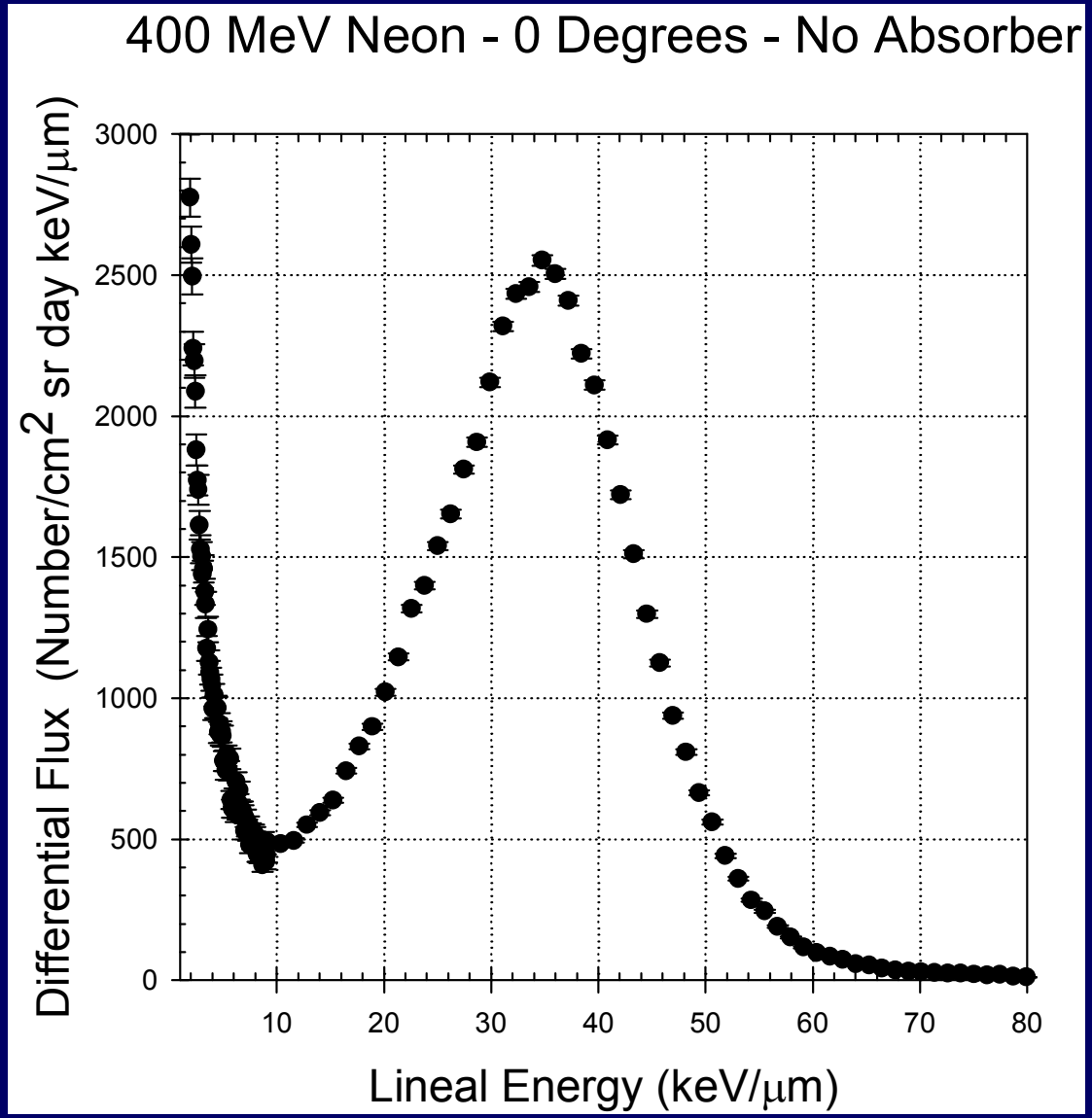

Node 1 - No Cyclic Data
TEPC Dose SM
+XVV +ZLV (LVLH)
-XPH+ZNN (XPOP)
+XVV +ZLV (LVLH)
-YVV +ZLV
+XVV +ZLV
Detector Horizontal
Detector Vertical
millirad
30
25
20
15
10
5
0
370.0
365.0
360.0
355.0
350.0
345.0
340.0
21.7
24.5
20.4
25.9
20.5
15.8
13.1
13.0
11.3
11.7
12.0
11.0
NODE
SM STBD CQ
SM P327
TEPC/R16
1.66
1.9
1.8
2.21
1.71
1.44
1.30
2/15/05
3/1/05
3/15/05
3/29/05
4/12/05
UT
4/26/05
5/10/05
5/24/05
6/7/05
Daily TEPC values > 97 %
Daily R-16 Values
Attitude Shift or TEPC Movement
TEPC Interval Averages by Attitude
R-16 Averages By Attitude
Alt (Km)

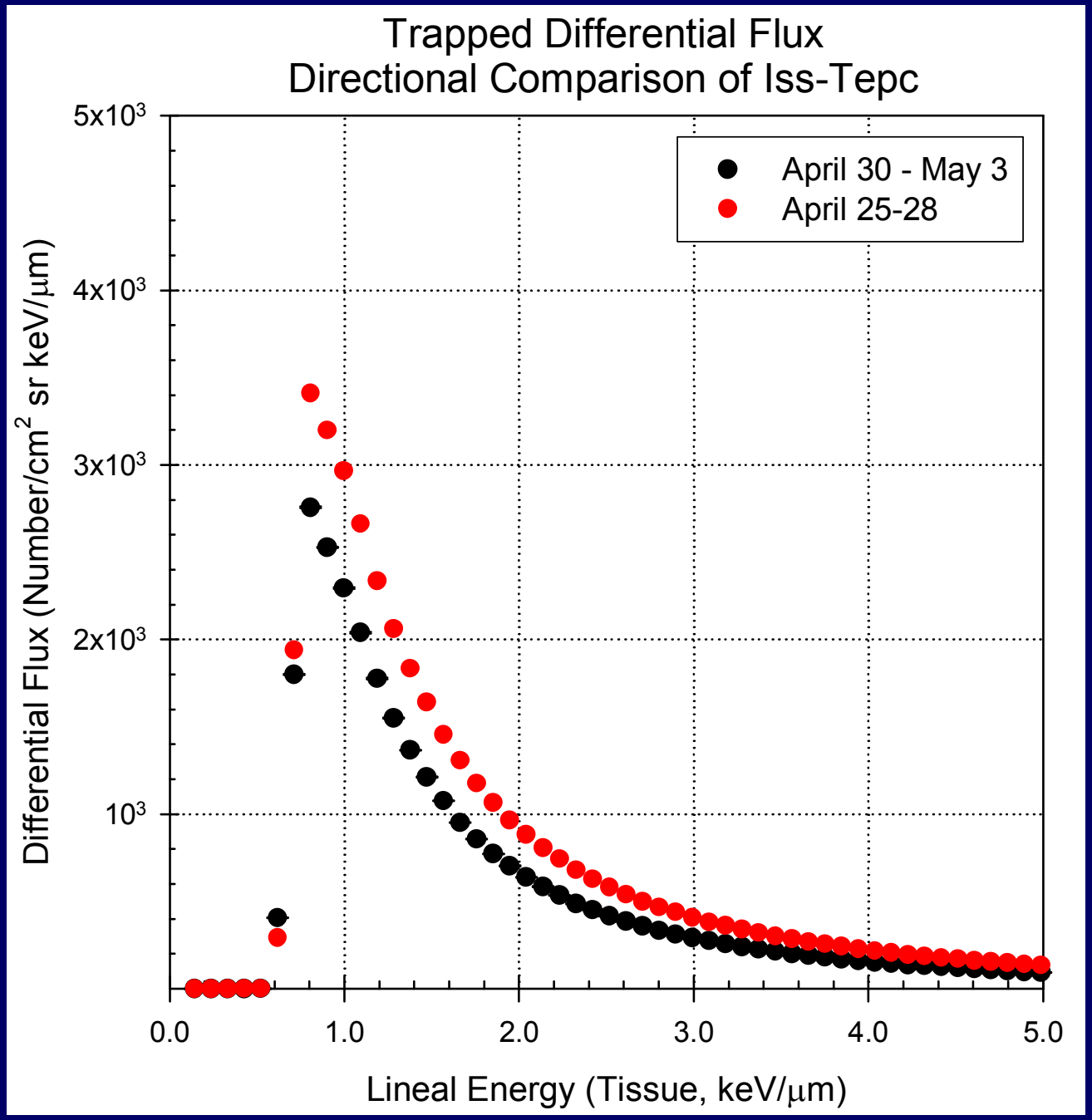

TEPC Daily Dose (> 97% coverage cyclic data)
TEPC Ratio
Current average /previous
(inverse)
1.35
.81 (1.24)
+XVV +ZLV
LVLH
-YVV +ZLV
LVLH
+XVV +ZLV
LVLH
-XPH +ZNN
XPOP
STS-114
Docked
20.9
20.8
17.0
15.8
15.5
16.2
16.4
11.9
12.7
11.0
millirads
Note: Previous TEPC
-YVV/+XVV =
1.27 (SM CQ Detector
Horizontal)
SM STBD
CQ
SM P 327
TEPC/R16
1.3
1.30
1.29
1.34
1.27
30
25
20
15
10
5
0
370.0
365.0
360.0
355.0
350.0
345.0
340.0
5/30/2005
6/19/2005
7/9/2005
7/29/2005
8/18/2005
9/7/2005
9/27/2005
Daily TEPC values > 98 %
R-16
Attitude Shift
Alt (Km)
TEPC Interval Averages by Attitude
R-16 Averages By Attitude
STS-114

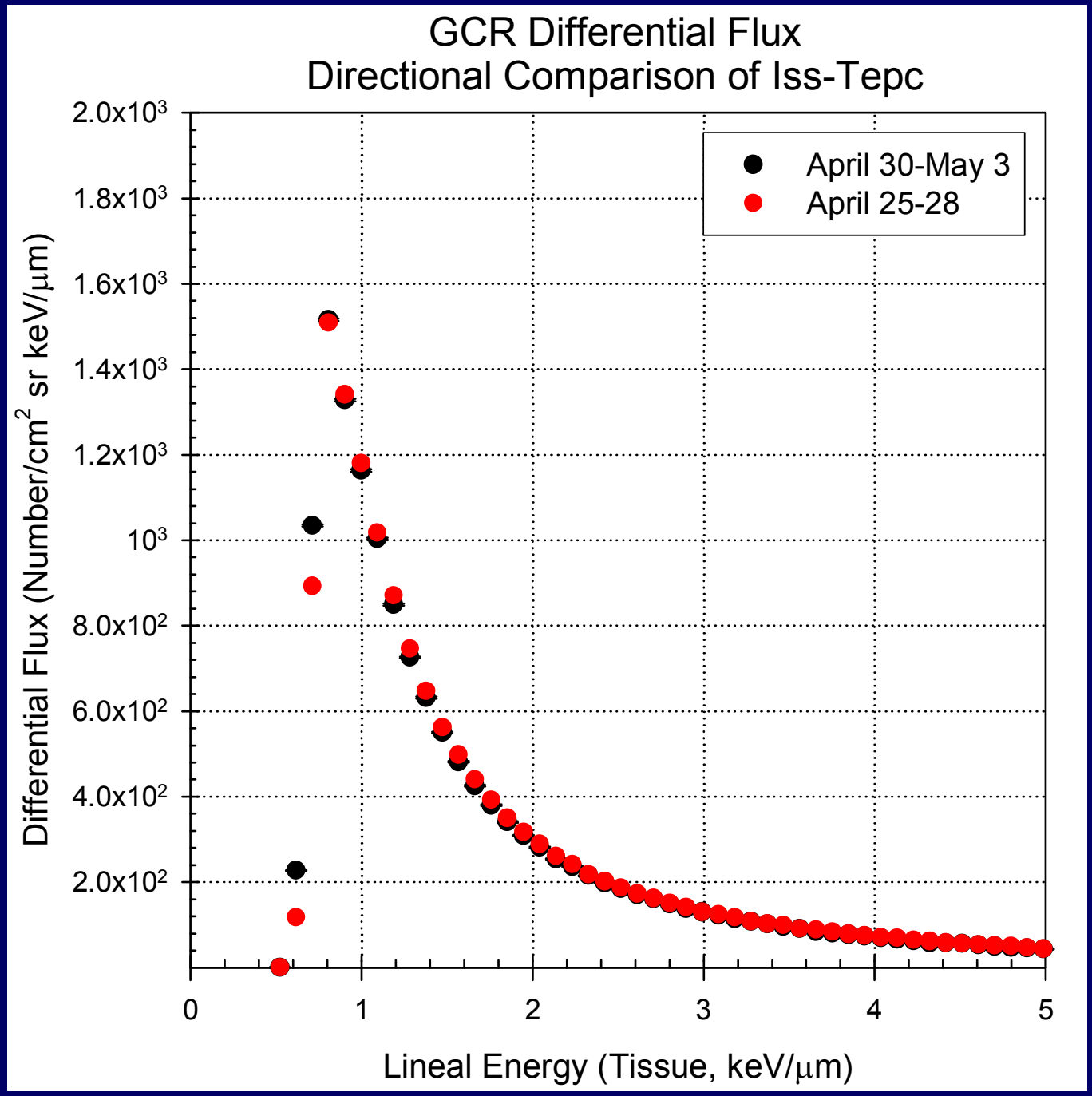
ICCHIBAN 3 Neon



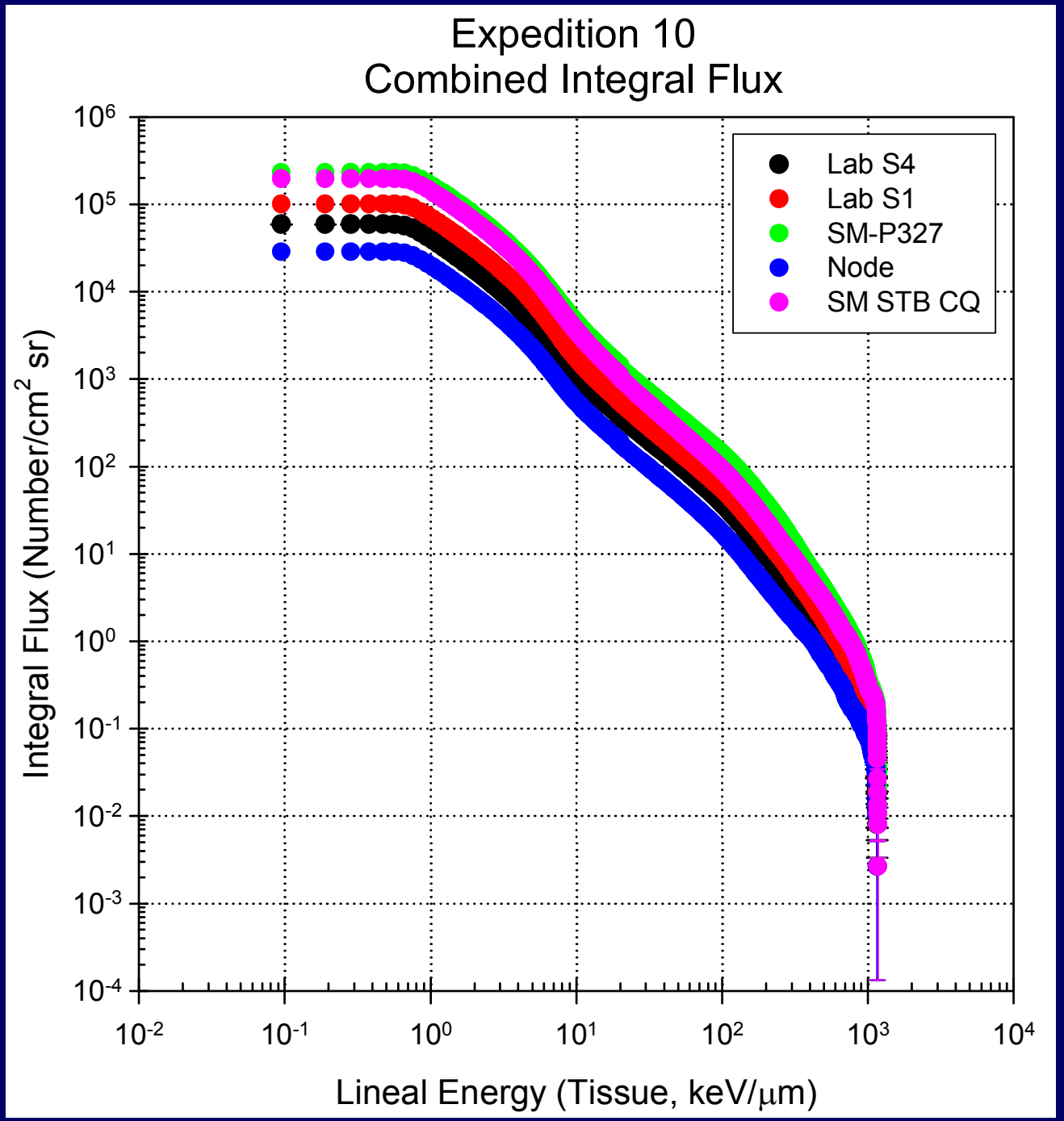
ICCHIBAN 3 Neon




Trapped Differential Flux
Directional Comparison of Iss-Tepc
April 30 - May 3
April 25-28
Differential Flux (Number/cm2 sr keV/μm)
5x10³
4x10³
3x10³
2x10³
10³
0.0
1.0
2.0
3.0
4.0
5.0
Lineal Energy (Tissue, keV/μm)

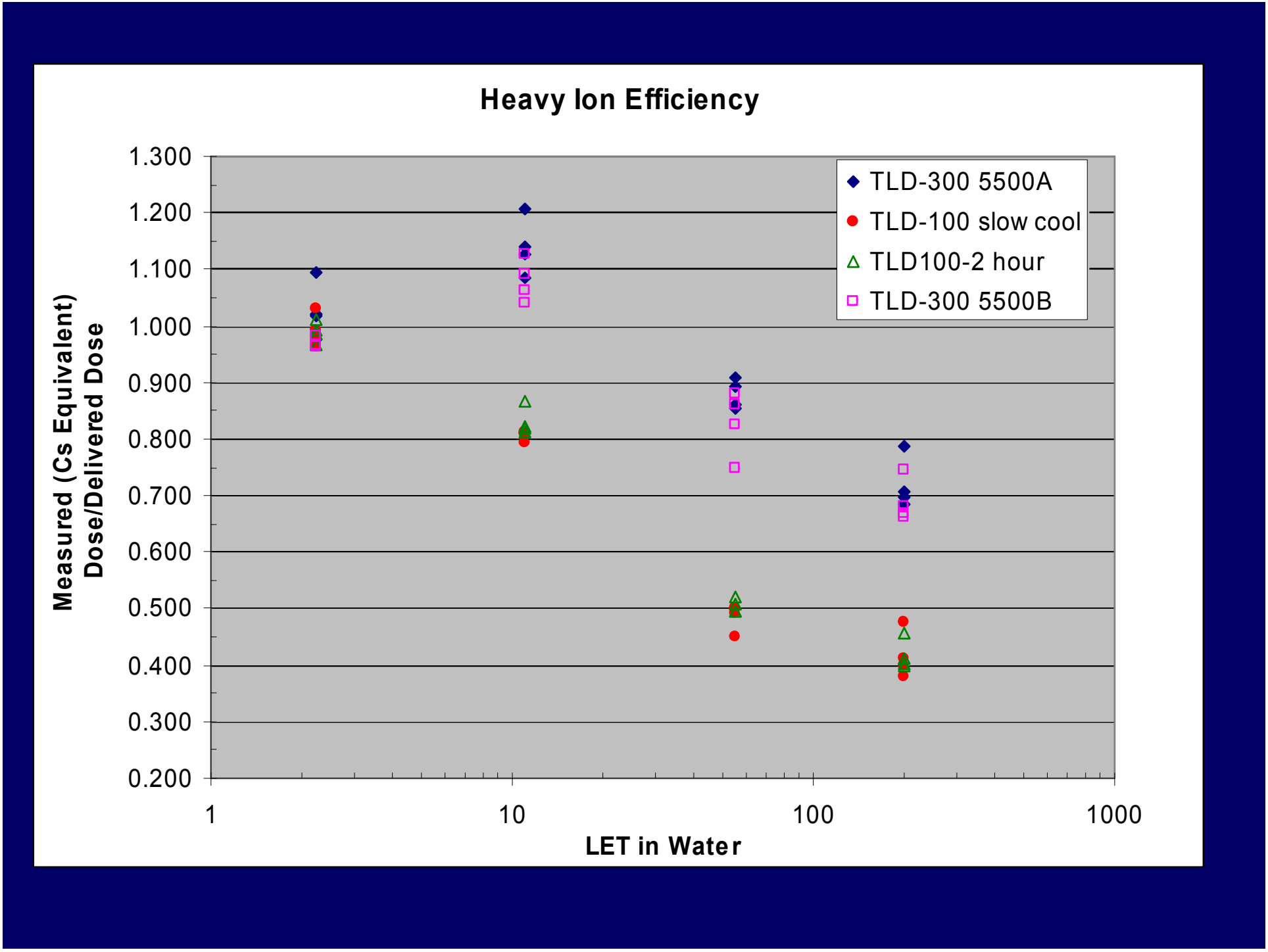

GCR Differential Flux
Directional Comparison of Iss-Tepc
April 30-May 3
April 25-28
Differential Flux (Number/cm2 sr keV/μm)
2.0x10³
1.8x10³
1.6x10³
1.4x10³
1.2x10³
10³
8.0x10²
6.0x10²
4.0x10²
2.0x10²
0
1
2
3
4
5
Lineal Energy (Tissue, keV/μm)

Total Dose (mGy)	Total Dose Equiv. (mSv)	Q
37.19	105.5	2.82



Expedition 10 CR-39 Simulation

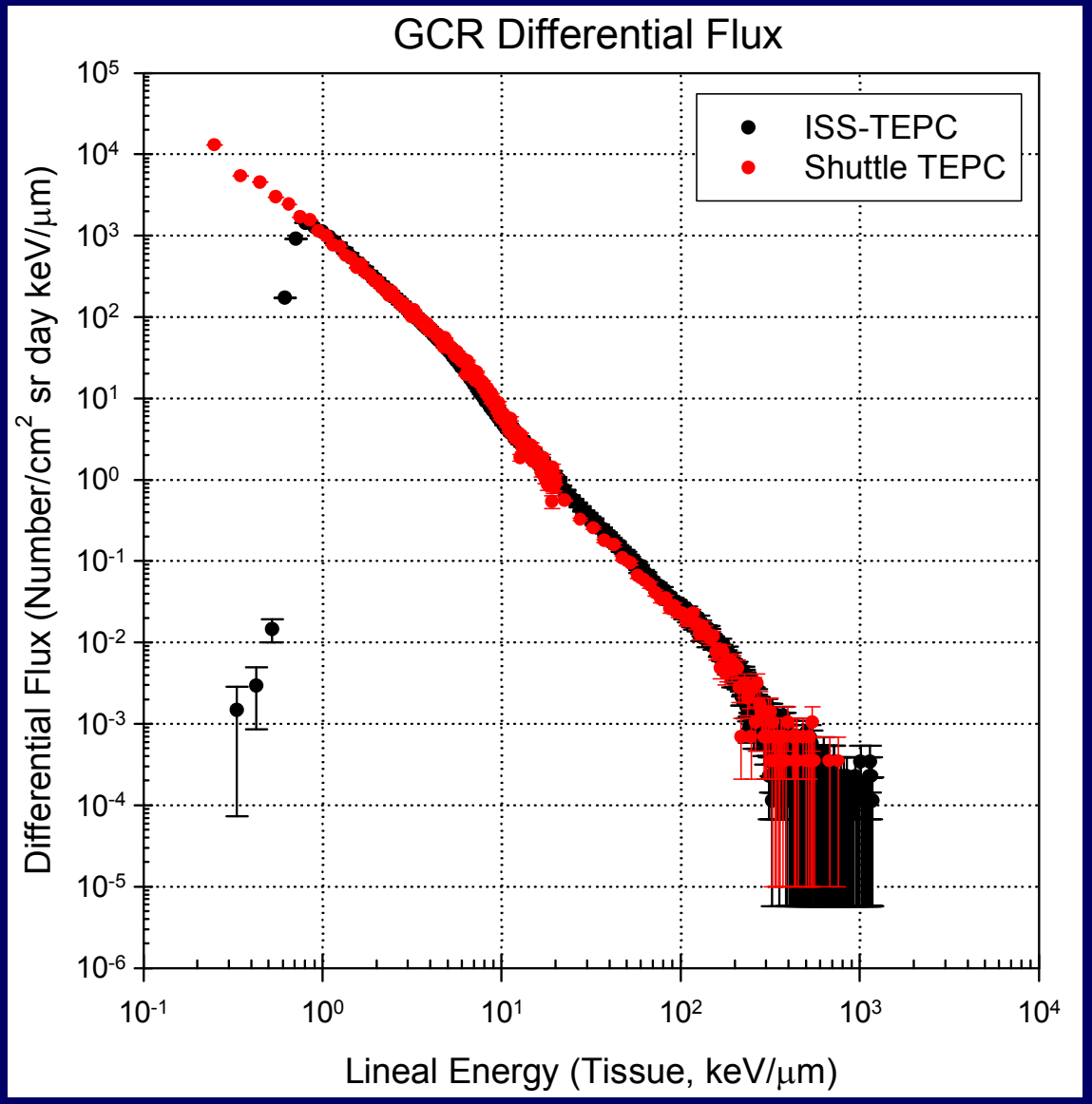
- D(TLD-300) is 38.9 mGy in 192.79 days, TEPC was operated for 16.28 days
  - D(TLD 300) for 16.28 days = 16.28 x (38.9/192.79) = 3.28 mGy
- D(TLD-100) for 16.28 days = 16.28 x (34.92/192.79) = 2.95 mGy


Heavy Ion Efficiency
Measured (Cs Equivalent) Dose/Delivered Dose
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
1
10
100
1000
LET in Water
TLD-300 5500A
TLD-100 slow cool
TLD100-2 hour
TLD-300 5500B

Comparison of TLD-TEPC combination

TLD	Average efficiency	D(total)/ D(low) (mGy)	D (TEPC) (mGy)	D (Total) (mGy)	H (Total) (mSv)	Q
300	0.754	3.28/ 2.83	0.601	3.43	9.56	2.78
100	0.582	2.95/ 2.59	0.601	3.20	9.33	2.91
TEPC				2.79	8.88	3.17

ISS/Shuttle TEPC Comparison-GCR



Expedition 10 Example

- NCRP 142, 2002 Equation 6.2

  Q derived from Tissue Equivalent Proportional Counter (TEPC) if PNTD not utilized:

  - SM-P327 Dose = 38.15 mGy

  Q measured by TEPC = 2.82

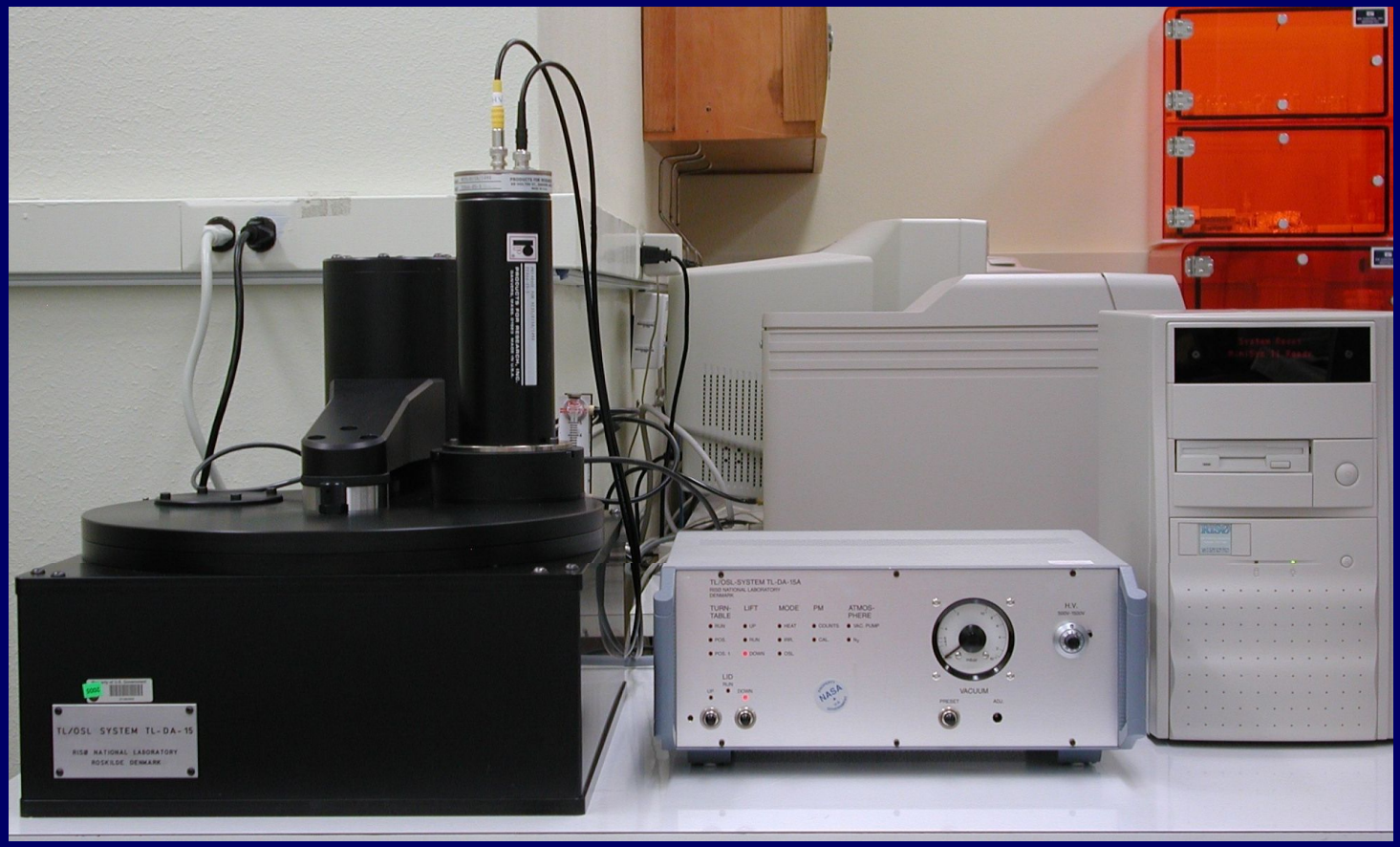
$$H \approx \frac{\overline{Q} D_{TLD}}{\overline{\varepsilon}}$$

H = 108 mSv for 193 day mission

Factors to consider:

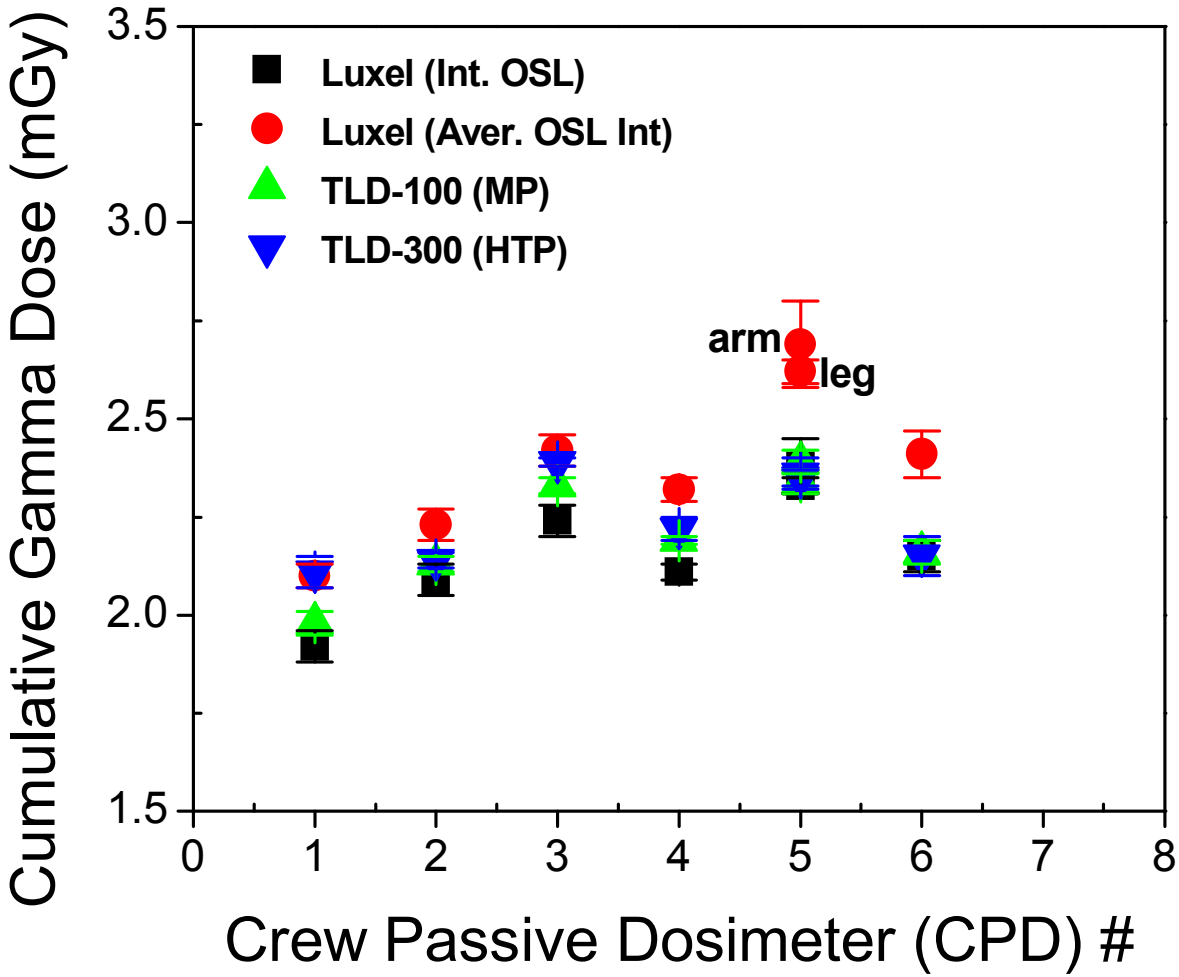
- *Depth Dose*
- *Quality Factors/Neutrons*

Risø TL/OSL-DA-15C/D Reader



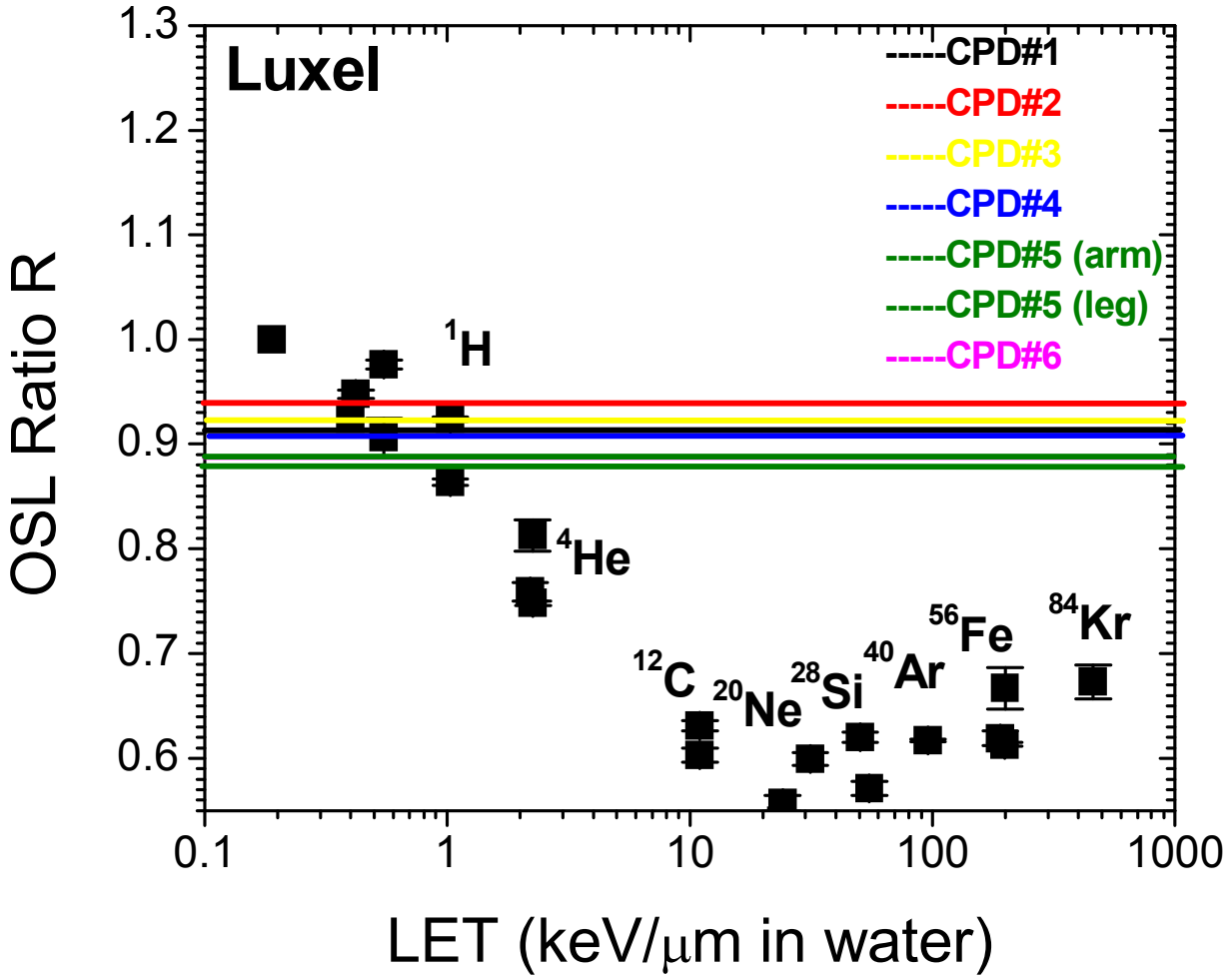
- OSL stimulation module: 49 Nichia Green Diodes (525 nm)
- Power at the sample of ~ 43mW/cm^2
- Emission filter Hoya U-340 (7.5 mm thick)

Preliminary STS-114 Results: CPD



- *Simplicity of OSL dot readout*

STS-114 Luxel Results



The bulk etch B* – the thickness removed by etching for one surface of the CR-39 plate, can be calculated by formula

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

where m_1 is the detector mass before etching, m_2, the mass after etching, T_2 is the detector thickness after etching, p is the detector perimeter and A is the detector surface area.

The etch rate ratio S is calculated by Somogyi's formula (Somogyi, 1977)

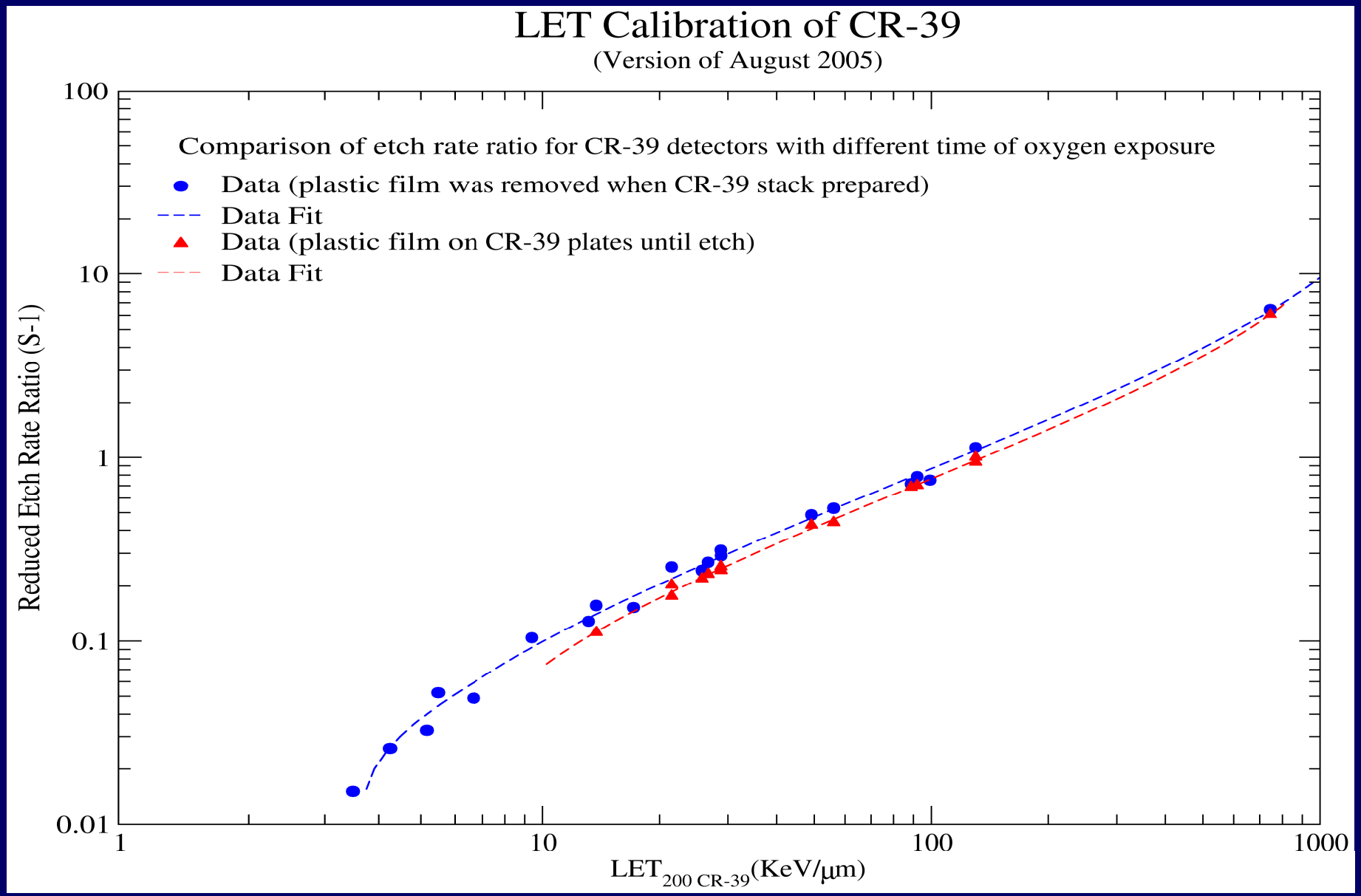
$$S = \sqrt{1 + 4\left(\frac{a}{2B}\right)^2 \Big/ \left[1 - \left(\frac{b}{2B}\right)^2\right]^2}$$

where a and b are the major and minor axes respectively.

*Etching: NaOH (6.25 N, 60oC) for 48 hours, B = 27 μm

LET calibration exposures for CR-39 (2004 – July 2005)

Institute	Ion	Energy	LET
		(MeV/n)	(keV/μm CR-39)
NSRL (BNL) (Sept. 04)	Proton	1000	0.147
	O	1000	9.39
	Fe	1000	99.20
HIMAC (March 05)	O	400	13.75
	Ne	400	21.49
	Ar	650	56.08
	Fe	500	130.10
	Xe	290	744.98
	He	150	1.54
TAMU (March 05)	Proton	14, 10, 8, 6, 3	2.60, 3.43, 4.14, 5.25, 9.50
		(Gev/n)	
BNL (July 05)	Si	0.3, 1, 3, 5, 10	49.19, 28.76, 25.73, 26.67, 28.81
	Fe	3, 5, 10	88.74, 92.01, 99.37


LET Calibration of CR-39
(Version of August 2005)
Comparison of etch rate ratio for CR-39 detectors with different time of oxygen exposure
Data (plastic film was removed when CR-39 stack prepared)
Data Fit
Data (plastic film on CR-39 plates until etch)
Data Fit
Reduced Etch Rate Ratio (S-1)
100
10
1
0.1
0.01
1
10
100
1000
LET200 CR-39(KeV/μm)

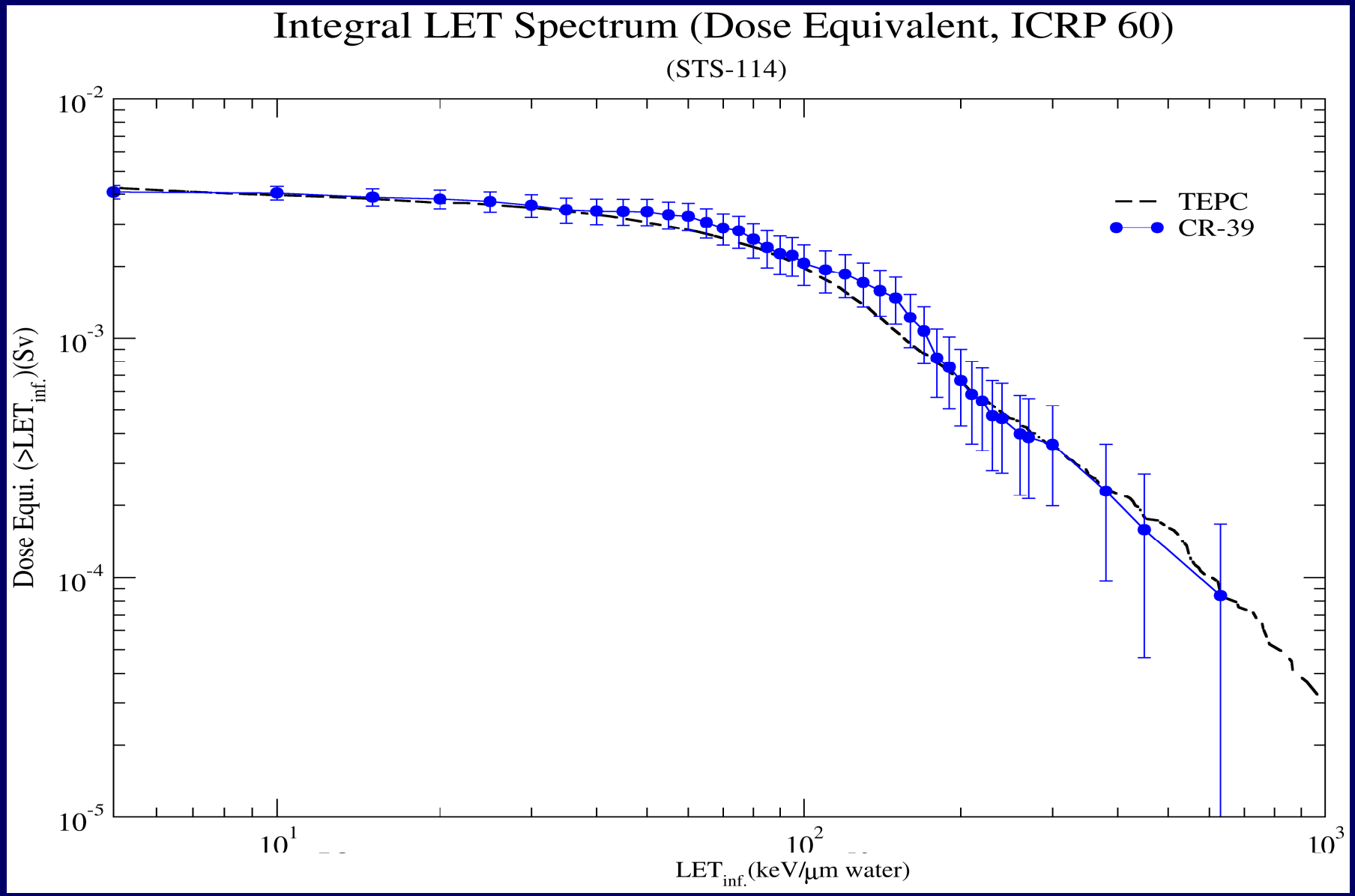
STS-114 TEPC Location Results

CR-39 detectors were used for STS-114 mission, some preliminary results were obtained using JSC CR-39 LET calibration and is listed below:

Results Measured by TEPC and CR-39

Location: JSC-TEPC	Dose Rate (≥ 10 keV/μm water)	Dose Equivalent Rate (≥ 10 keV/μm water) (ICRP 60)	Quality Factor
	(μGy/day)	(μSv/day)	
TEPC	24.83	278.86	11.23
CR-39	23.81	291.00	12.22

Integral spectra of dose equivalent measured by TEPC and CR-39



STS-114 TEPC Results, full LET spectrum

	GCR			Trapped			Total		
	Dose Rate (μGy/day)	Dose Equivalent Rate (μSv/day)	Quality Factor	Dose Rate (μGy/day)	Dose Equivalent Rate (μSv/day)	Quality Factor	Dose Rate (μGy/day)	Dose Equivalent Rate (μSv/day)	Quality Factor
ICRP-60	94.502	302.276	3.20	46.975	93.240	1.98	141.477	395.516	2.80

Shuttle TEPC/Crewmember CR-39 Results

Preliminary Results of STS-114 from CR-39 Plates
(≥ 10 keV/μm water, ICRP 60)

CR-39 Plate	Dose	Dose Rate	Dose Equivalent	Dose Equivalent Rate	Q
	(mGy)	(μGy/day)	(mSv)	(μSv/day)	
Near TEPC	0.3310	23.81	4.0449	291.00	12.22
Collins	0.3376	24.29	4.1659	299.71	12.34

Future Work

- Continued investigation of Optically Stimulated Luminescence (OSL) of Al2O3:C detectors, leading to use as primary low LET dosimeter
- Operational Use of Plastic Nuclear Track Detectors CR-39 to determine dose equivalent at surface of the astronaut directly
- STS-114 is first mission to have full complement of TLD/OSL/CR-39, analysis of track detectors, OSLD, and TLD underway