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High dose applications of Radio-Photoluminescent (RPL) dosimeters: X-ray irradiations up to the MGy

M. Ferrari, Y.Q. Aguiar, A. Raj, A. Hasan, A.K.Alem, A. Morana, C.Campanella, A.Donzella, L.Sostero, D.Pagano, A.Zenoni, R.García Alía, S.Girard

Radopt 2023
Toulouse
30-11-23

International Collaboration

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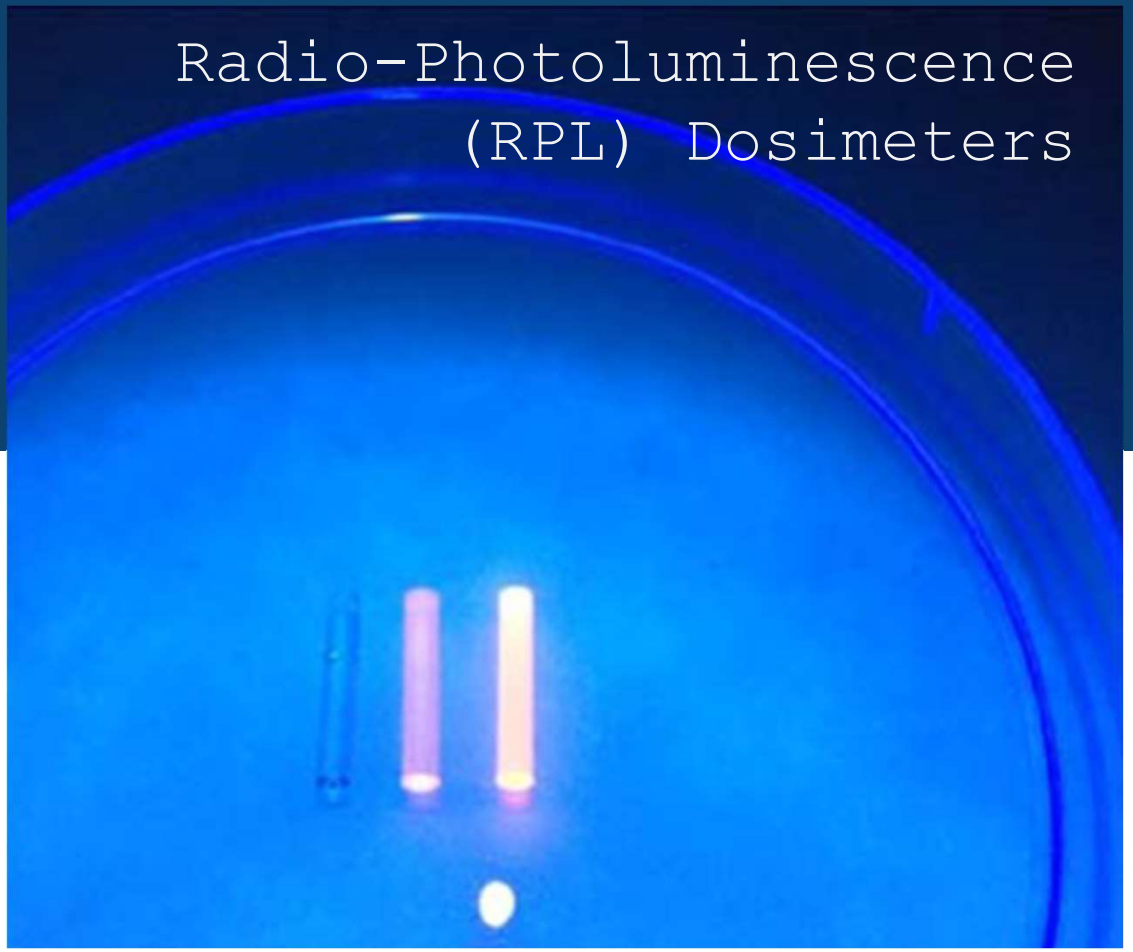
CERN

New research line since **2023**



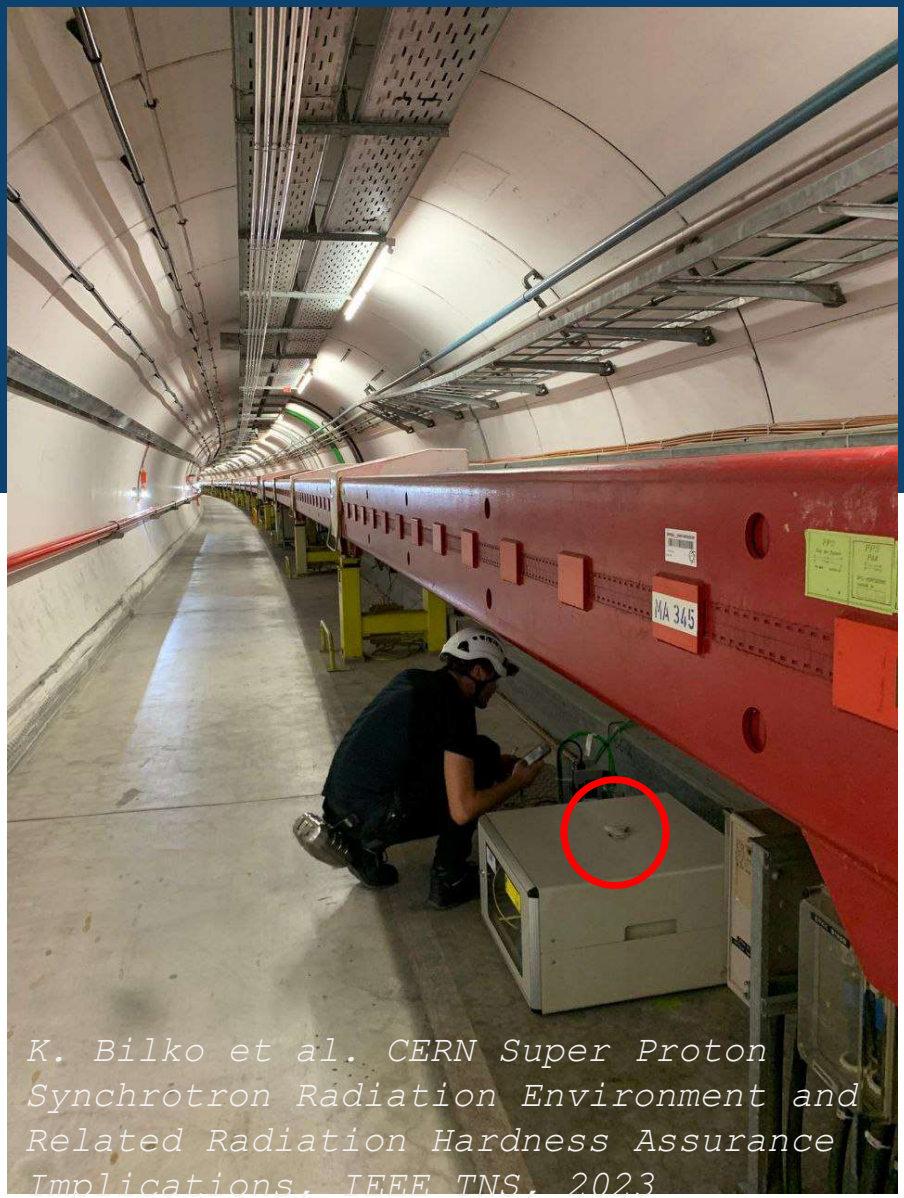
D. Pramberger, et al., "Characterization of Radio-Photo-Luminescence (RPL) Dosimeters as Radiation Monitors in the CERN Accelerator Complex," in IEEE TNS, vol. 69, no. 7, pp. 1618-1624, 2022.

RPL: passive monitoring in high radiation areas

1.5 mm x 8.5 mm

- **FD-7 glass rod**
- **Ag doped** P glasses
- **Linear** response up to **10-500 Gy**

Used since 2012

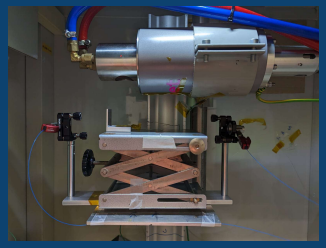


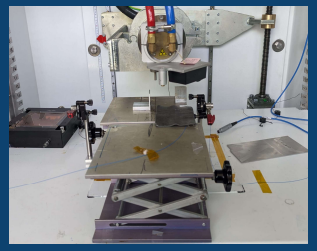
K. Bilko et al. CERN Super Proton Synchrotron Radiation Environment and Related Radiation Hardness Assurance Implications, IEEE TNS, 2023

Experimental Characterisation

- **High dose** (**kGy to MGy**)
- **X-ray** radiation
- **Dose rate** variations
- **On-line** measurements
- **Multi-wavelength**

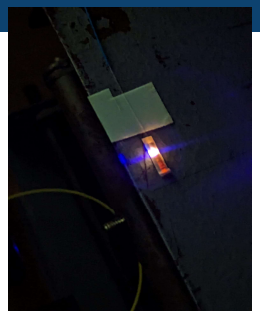
A.Hasan, Master Thesis (2023)





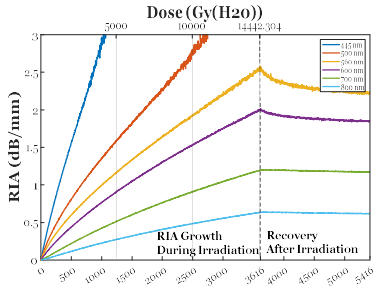
Transmission & online RPL response

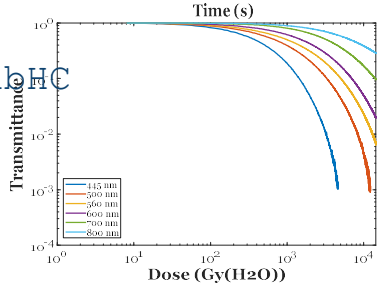
Sample holder



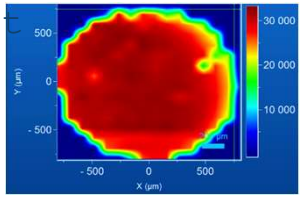
Offline RPL measurement

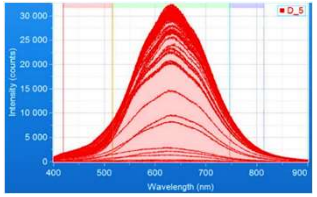
X-ray chamber at LabHC





Online characteriza





Confocal microscopy: RPL measurement

Master RADMEP

Erasmus+

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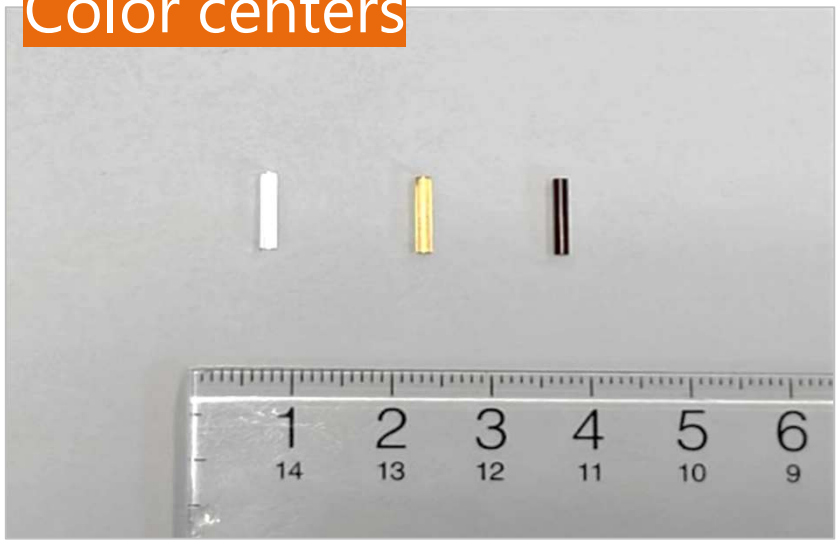
Two main Radiation Effects in RPLD

Luminescence centers

RPL signal

Color centers



Signal attenuation

Acknowledgement: J. Trummer, CERN

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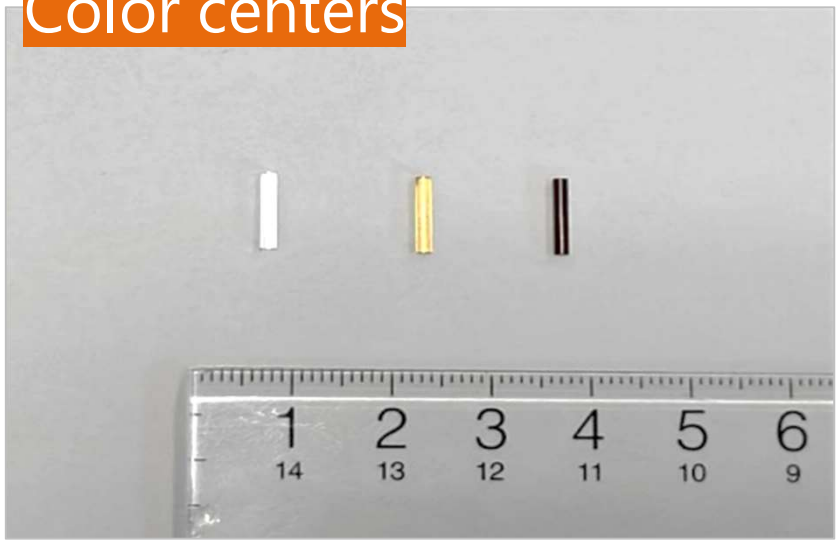
Two main Radiation Effects in RPLD

TODAY'S PRESENTATION

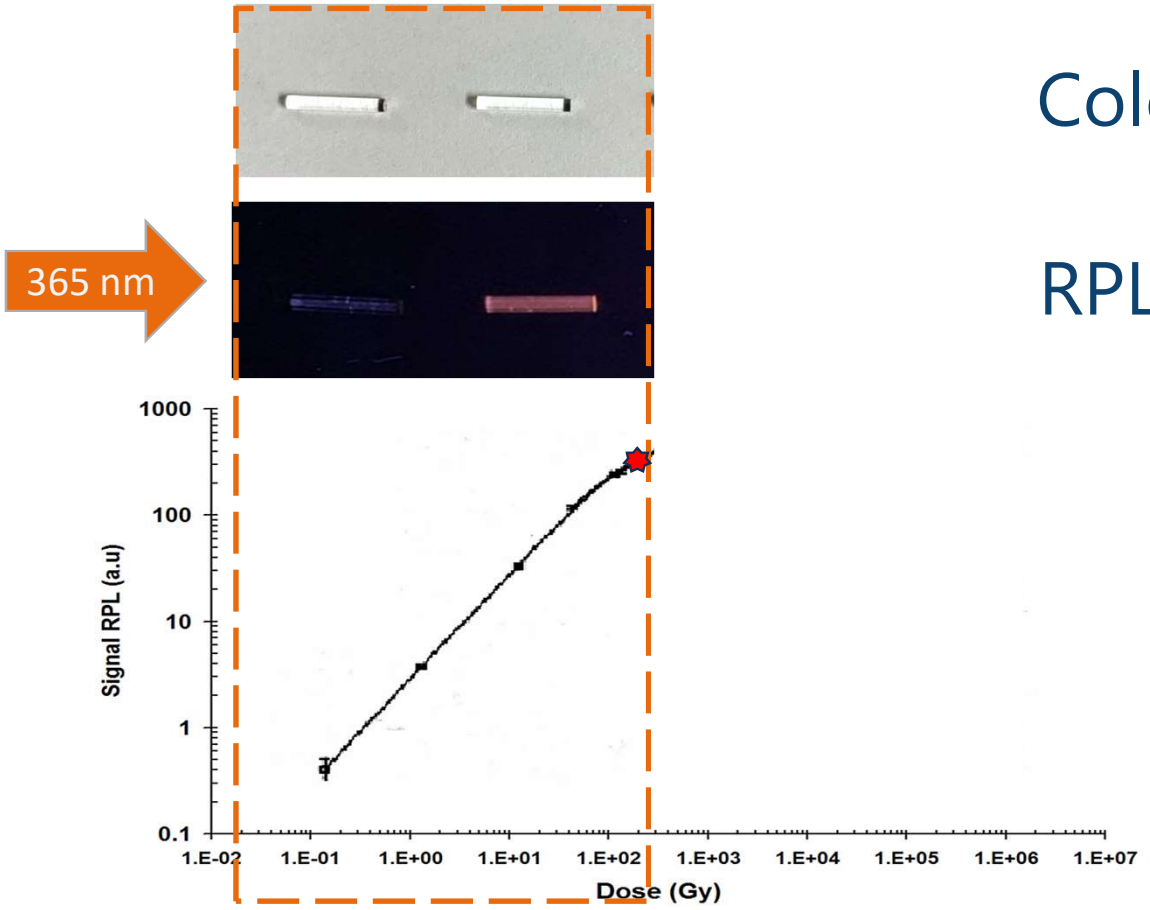
Color centers



Signal attenuation

RPL response vs dose

- **FD-7 glass rod**
- **Ag doped** P glasses
- **Linear** response up to **10-500 Gy**



Color

RPL signal

DOSE RANGE LOW

M. Fuerstner et al. "High-Level Dosimetry systems used at CERN." (2004)

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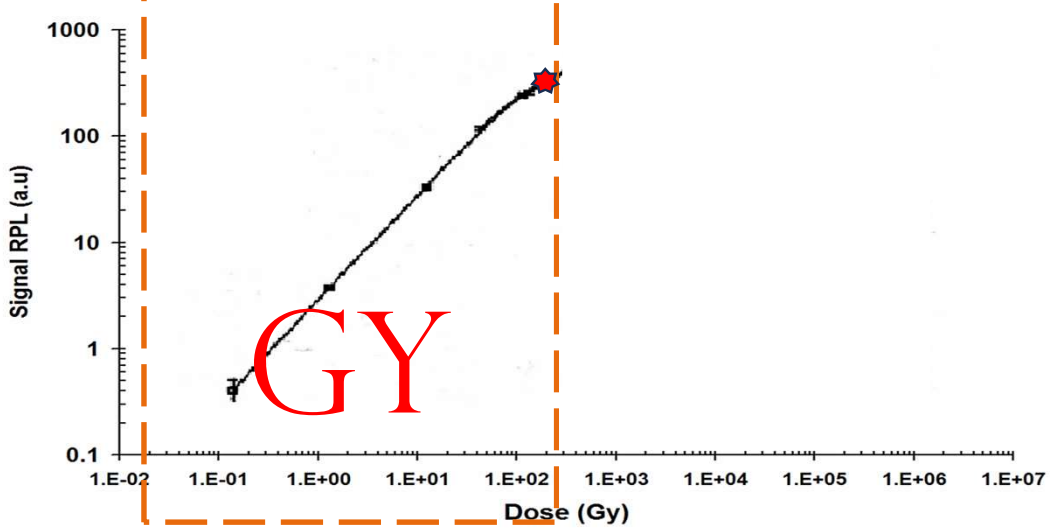
USUAL RANGE OF APPLICATION

RPL signal

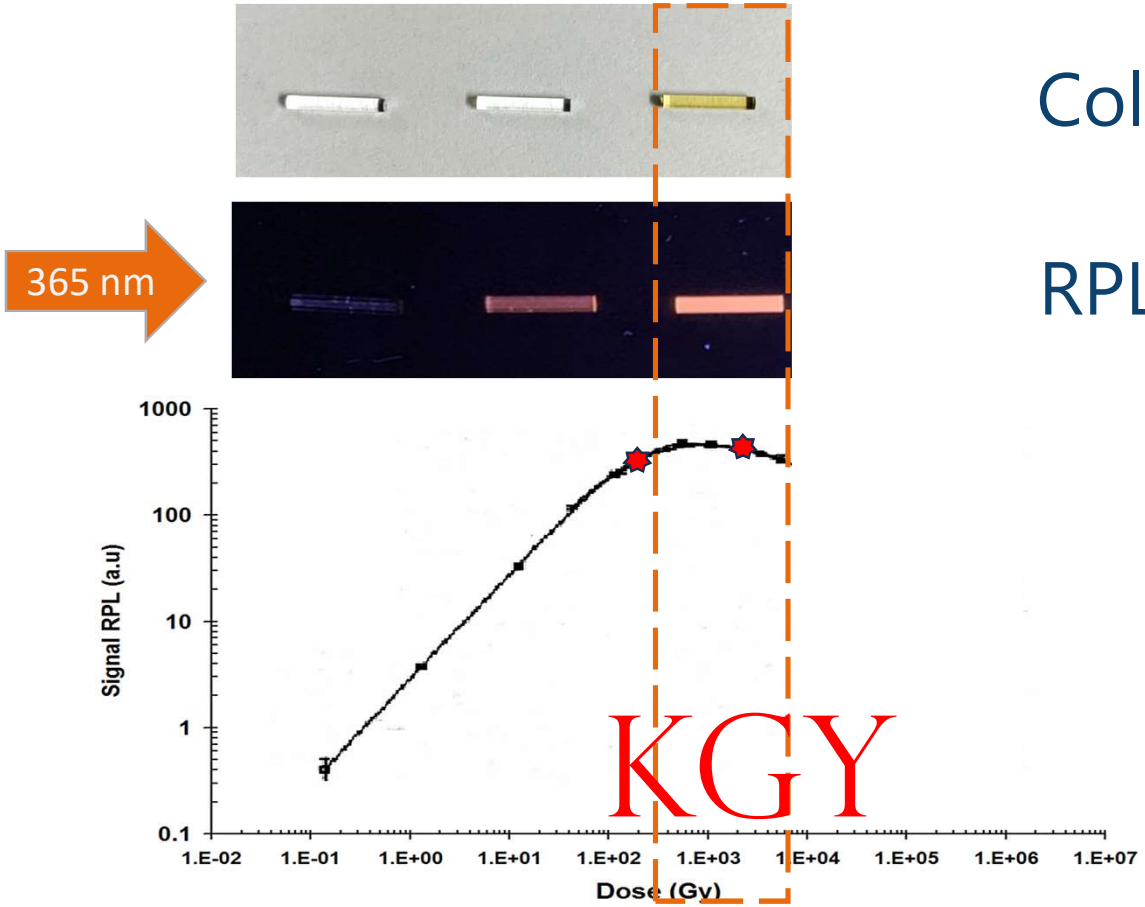


GY

DOSE RANGE LOW

M. Fuerstner et al. "High-Level Dosimetry systems used at CERN." (2004)

RPL response vs dose



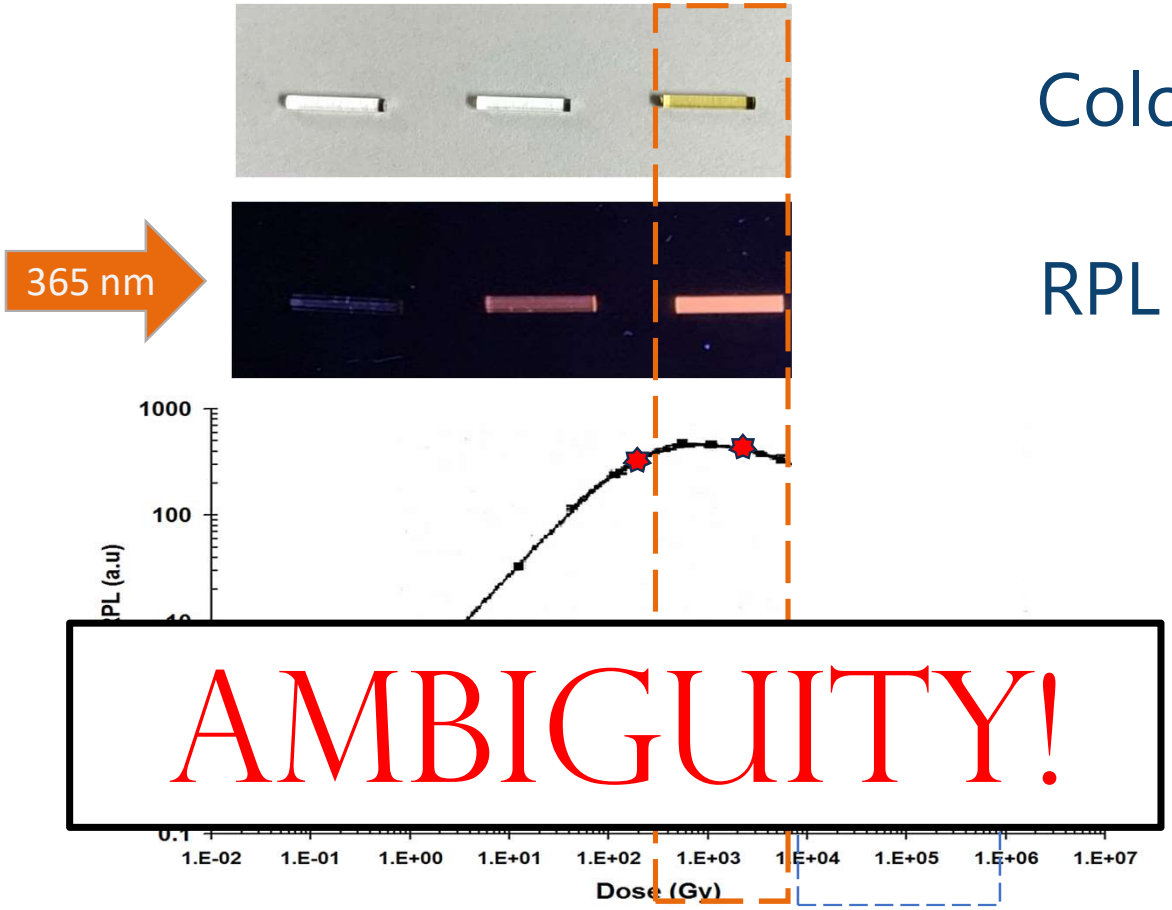
Color

RPL signal

DOSE RANGE

MEDIUM

RPL response vs dose



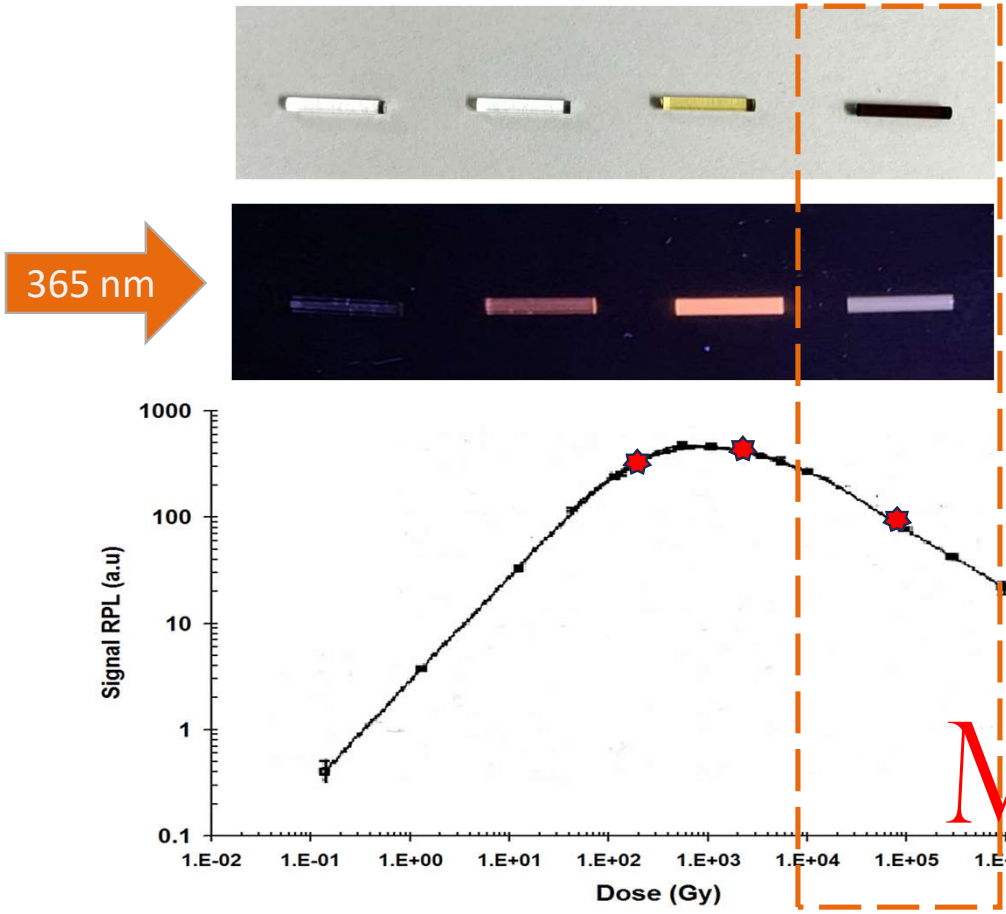
Color

RPL signal

DOSE RANGE

MEDIUM

RPL response vs dose

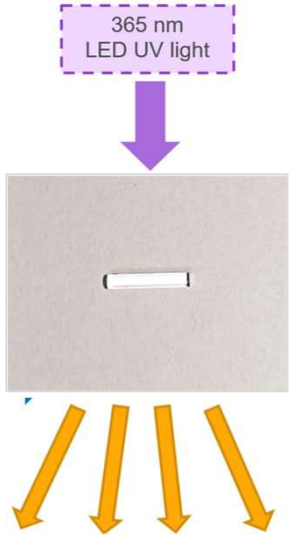


DOSE RANGE

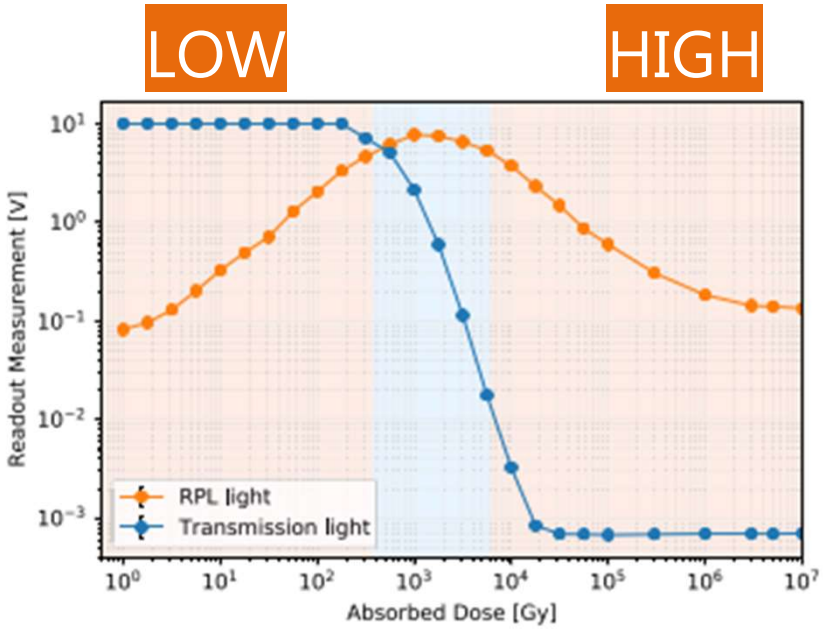
HIGH

How to extend RPL readout range?

1. RPL signal



Proportional to dose



D. Pramberger, et al., IEEE TNS, vol. 69, no. 7, pp. 1618-1624,

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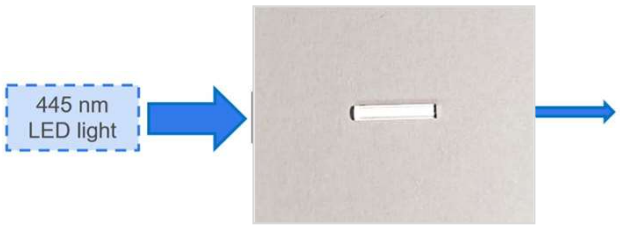
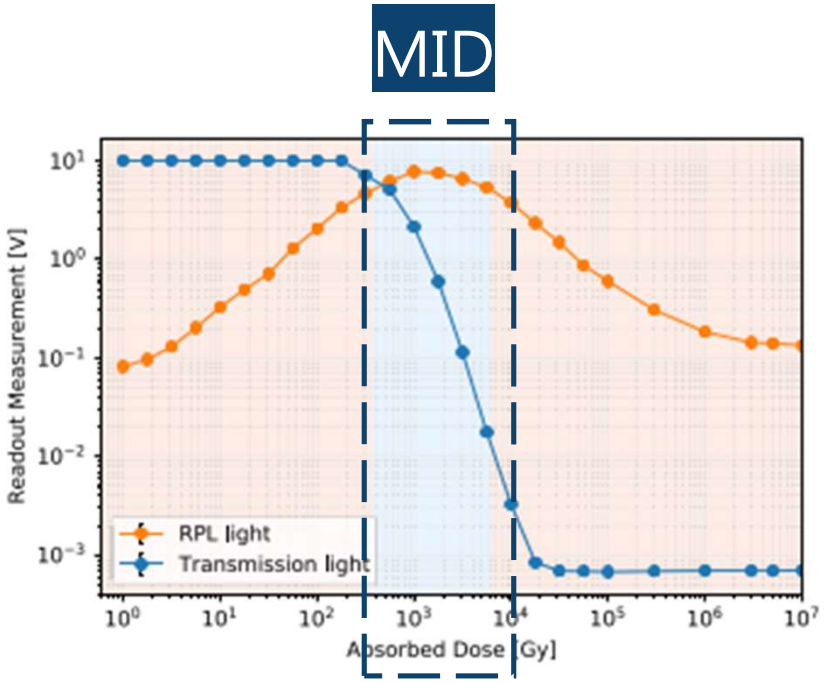
How to extend RPL readout range?

1. RPL signal
2. Transmitted signal



Attenuation due to glass darkening

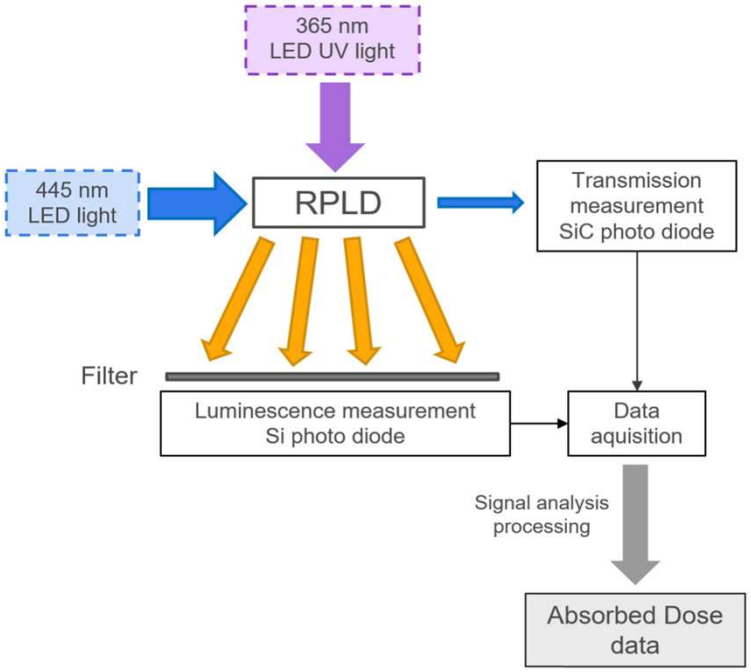


AMBIGUITY IS SOLVED

2-light system used at CERN

- Adapted readout
- Patented 2014
- **445 nm** selected for transmission
- **Up to MGy doses**

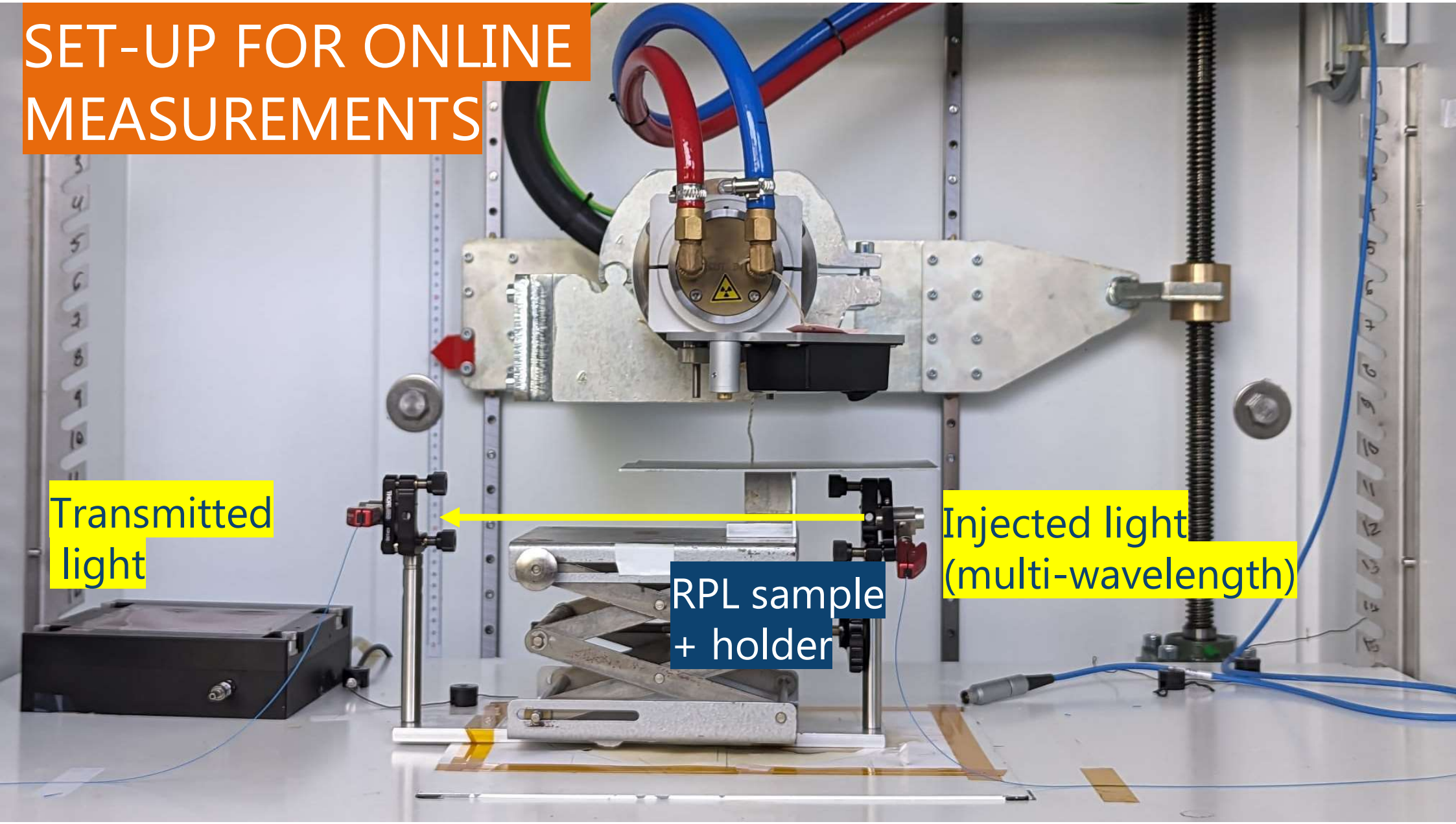
Motivates further transmission studies

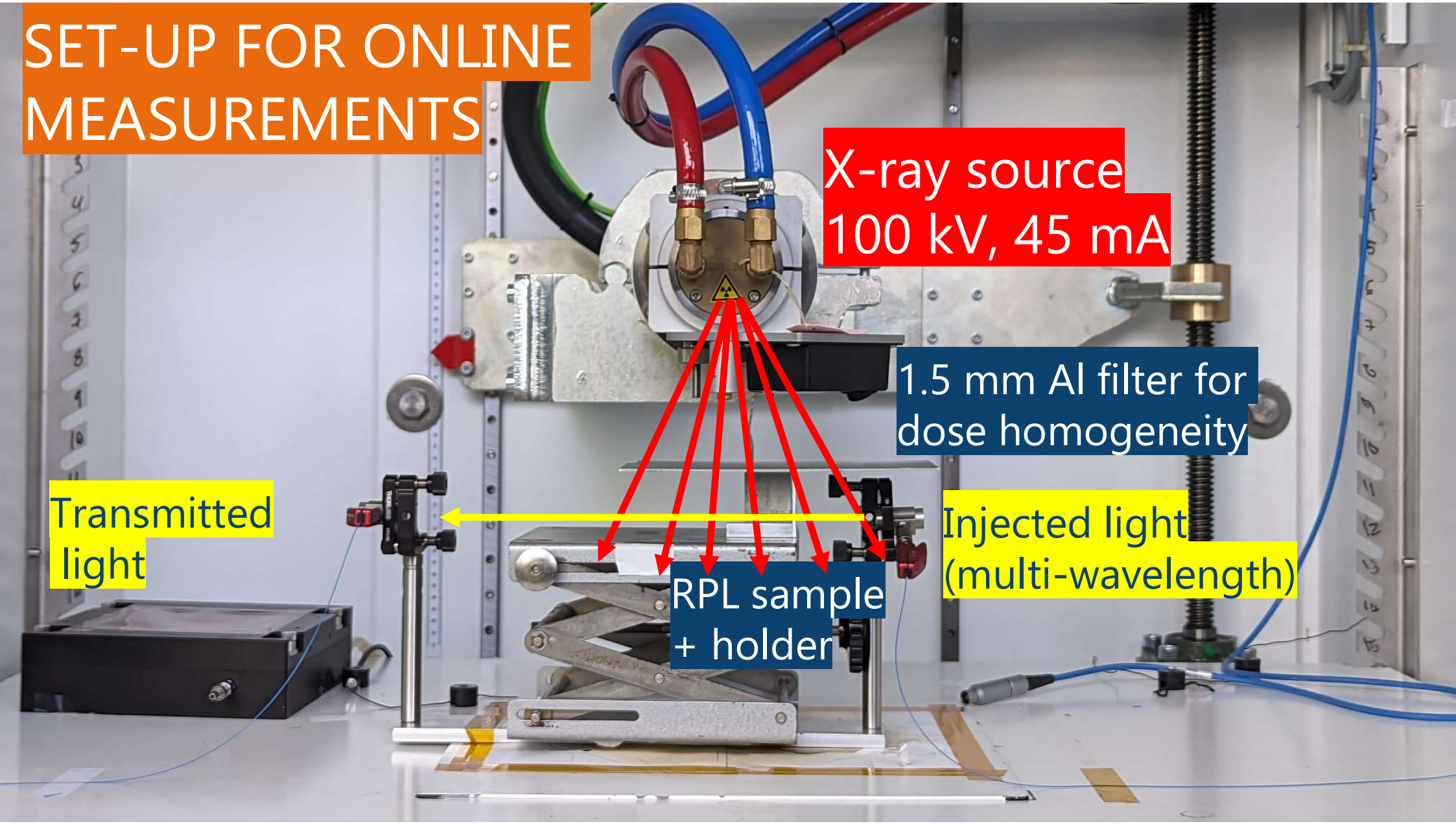


H. Vinke and J. Trummer, "Apparatus and method for determining a dose of ionizing radiation."
WO ***Patent*** *2 014 161 732, Sep. 10, 2014*

SET-UP FOR ONLINE MEASUREMENTS

SET-UP FOR ONLINE MEASUREMENTS



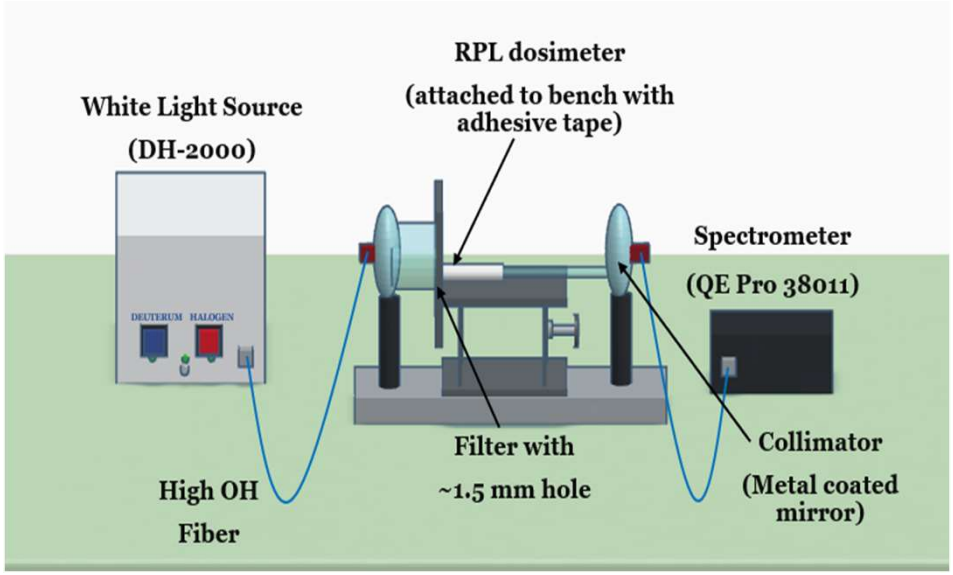

SET-UP FOR ONLINE MEASUREMENTS
X-ray source
100 kV, 45 mA
1.5 mm Al filter for dose homogeneity
Transmitted light
Injected light (multi-wavelength)
RPL sample + holder

Radiation Induced Attenuation

$$RIA\ (t,\lambda) = -\left(\frac{10}{l}\right) \times \log_{10}\left(\frac{I(t,\lambda) - I_N}{I_{ref}(0,\lambda) - I_N}\right)\ [dB/mm]$$

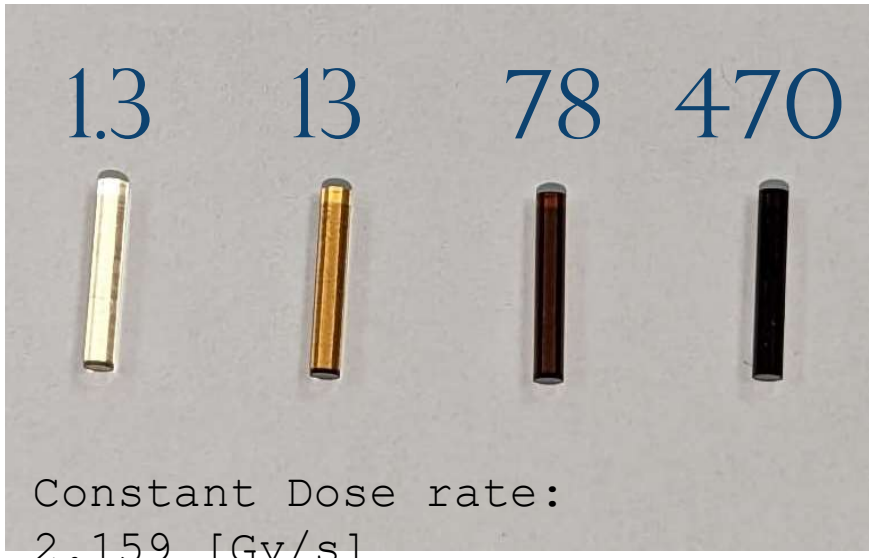
- **Online RIA** (during irradiation)
- **RECOVERY** (3 hours after irradiation)
- **POST-MORTEM** (some days after irradiation)

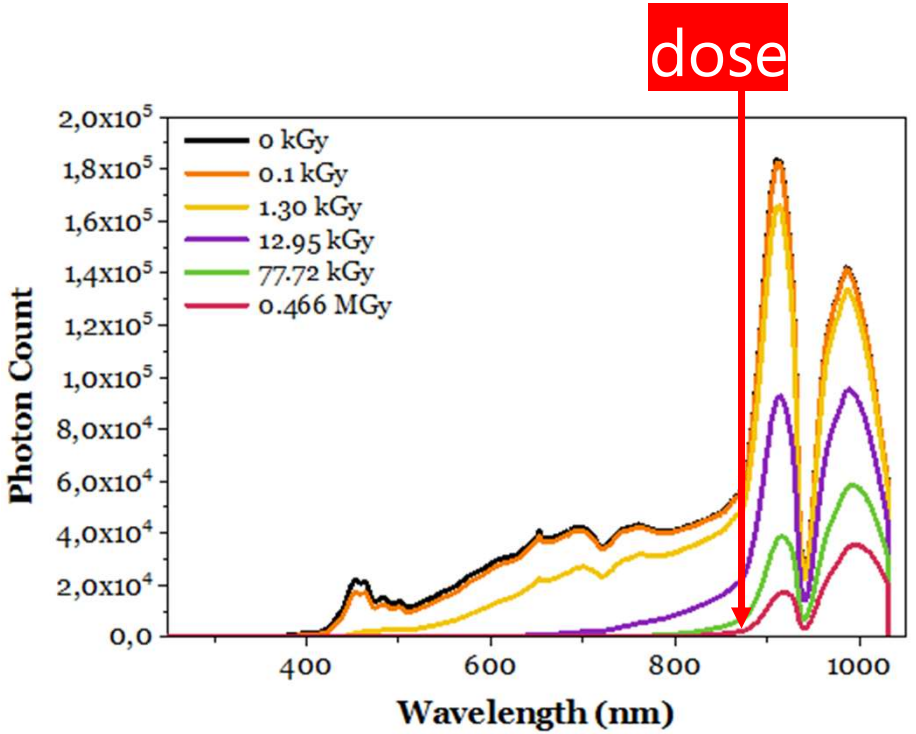
Relative quantity for the transmitted signal



Adapted from: T. Allanche, "Effect of high radiation doses (MGy) on light Emitting Diodes and optical glasses.", PhD Thesis (2021)

Transmitted signal vs dose





CALIBRATION & DOSIMETRY:

M. Ferrari, et al., accepted to RADECS 2023, in preparation for IEEE TNS submission (Sept 2023)

Intensity attenuation with dose at all λ

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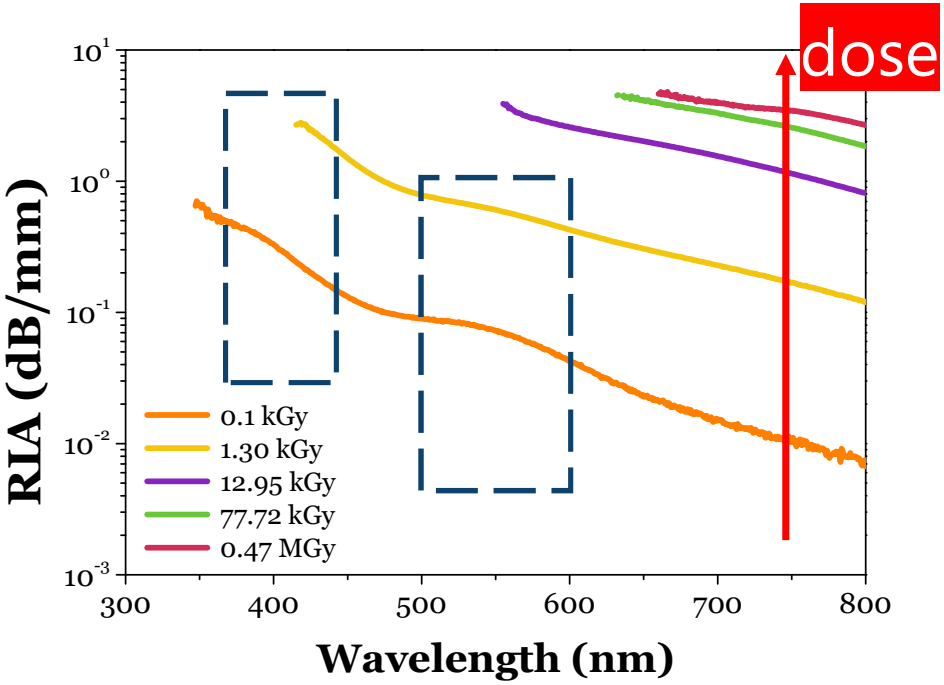
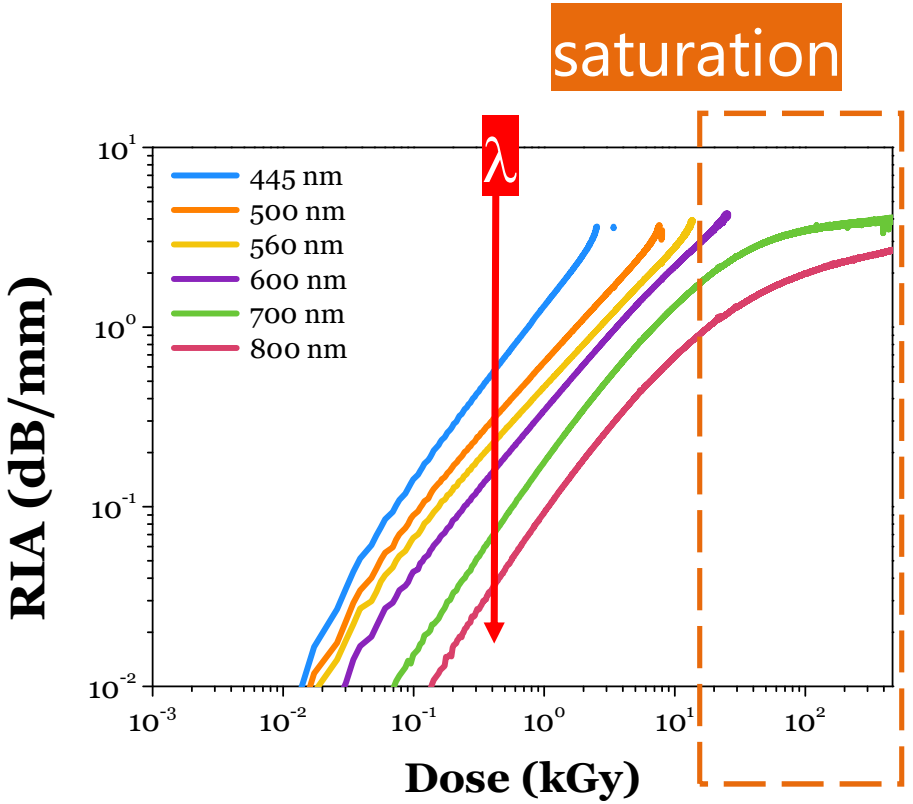
Spectral RIA vs dose





Optical bands at low dose – metastable defects?

RIA increases with dose
Higher at lower λ

A.Hasan, RADMEP Master Thesis

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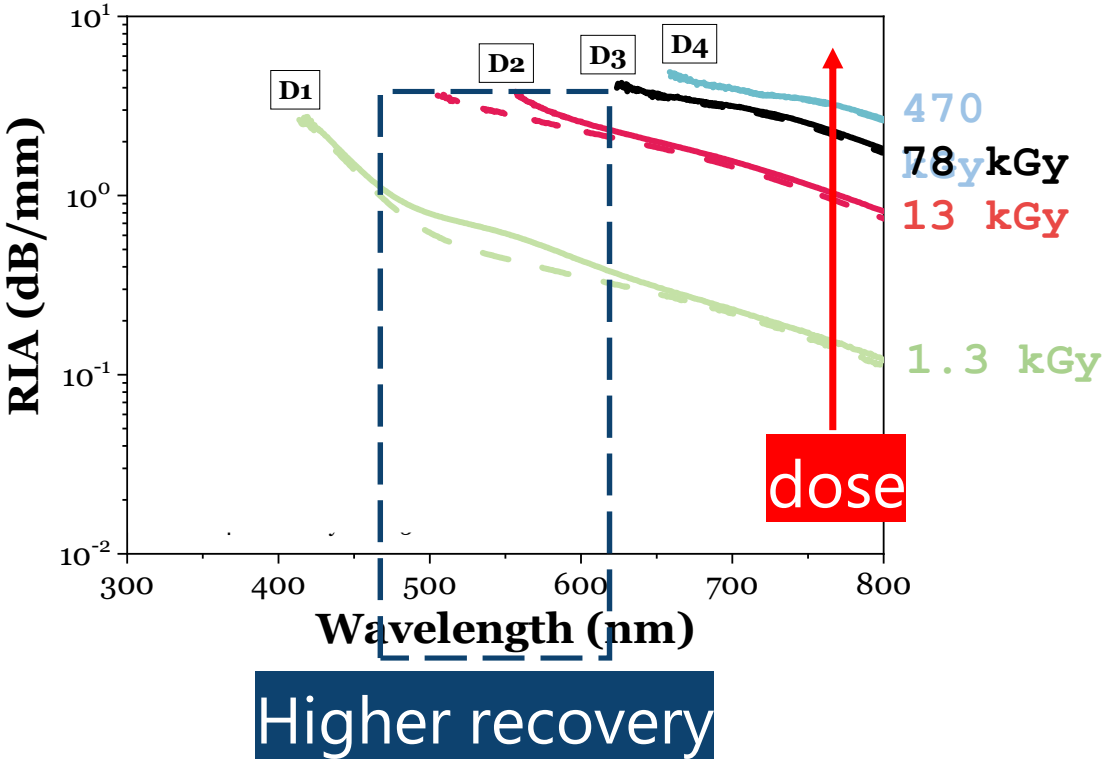
Recovery as a function of the dose



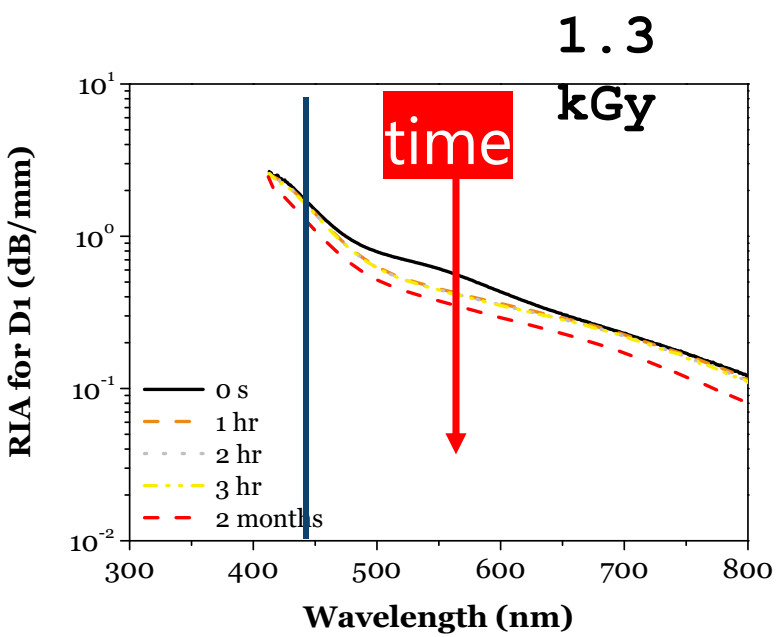
End of irradiation

3h after end of irradiation

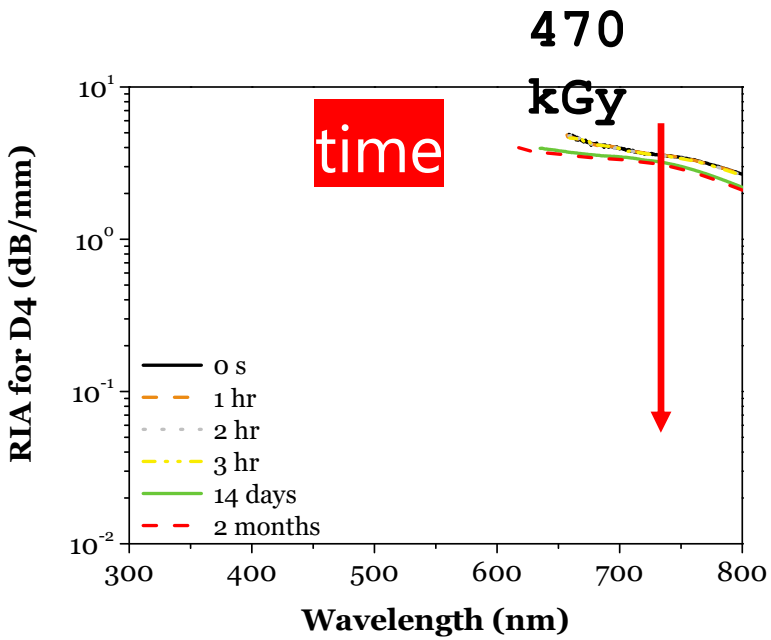
Higher Recovery at lower doses

A.Hasan, RADMEP Master Thesis

Post-mortem up to 2 months: examples



Might impact dose readout!



Recovery saturation reached in 14 days

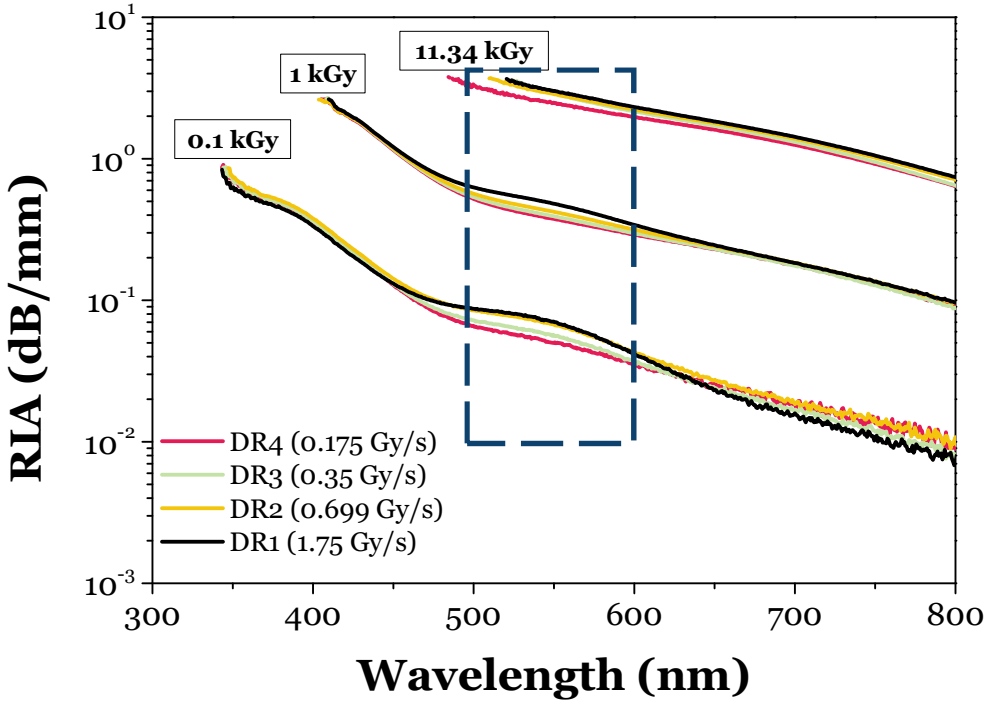
A.Hasan, RADMEP Master Thesis

Dose rate study at doses up to 11 kGy

Rates [Gy/s]:

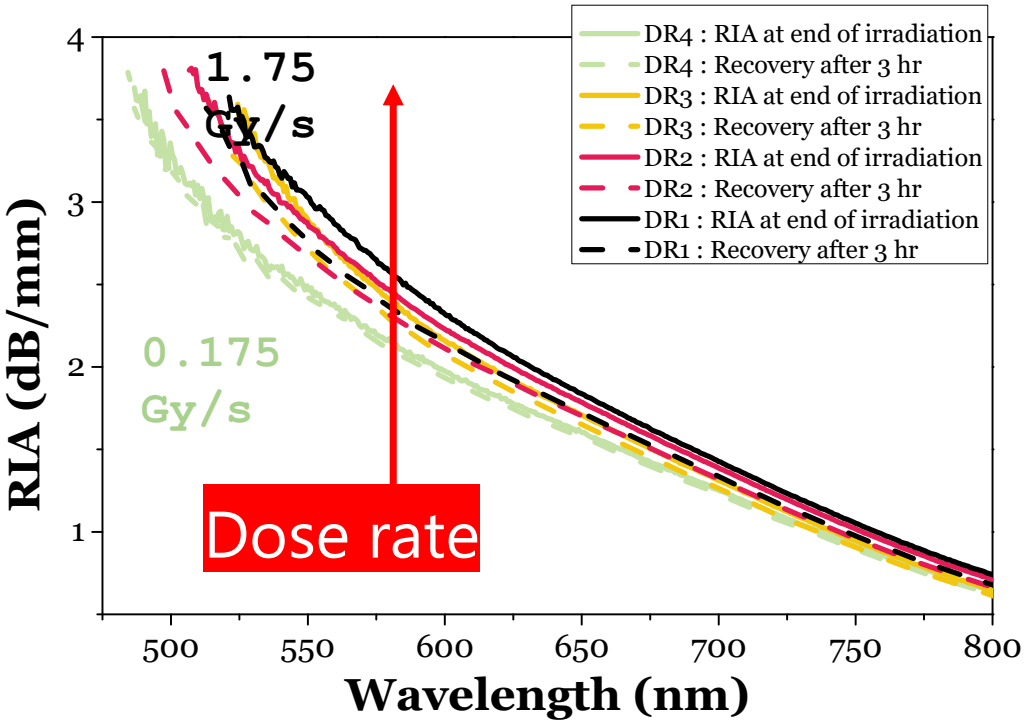
- 1.75
- 0.7
- 0.35
- 0.175

CALIBRATION & DOSIMETRY:
M. Ferrari, et al., RADECS 2023



Dose rate effect depending on λ

RIA and recovery as a function of the dose rate



Dose rate response: little literature

Higher dose rate effect (but also higher recovery) at high dose rates

To be further studied (post mortem…)

A.Hasan, RADMEP Master Thesis (2023)

Summary and Take home messages

- **Set up for on-line tests;**
- **High dose range –** MGy;
- **X-ray** irradiators used;
- **Multi-wavelength** analysis;
- **Recovery:** impact on dosimetry;
- **Dose rate effect:** to be further studied;
- Margins to **refine/extend the readout**
- Future studies: target **on-line RPL signal**, temperature effects, other RPL materials...
- Variety of applications in **high**

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THANK YOU FOR YOUR ATTENTION!

Prof. Matteo Ferrari
matteo.ferrari@univ-st-etienne.fr

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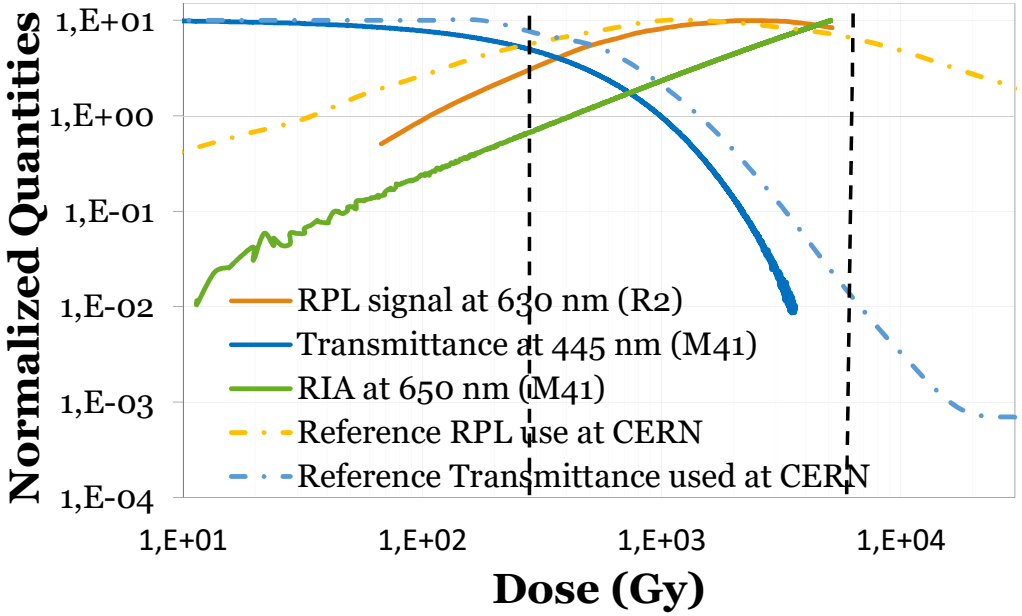
CERN

Open for collaborations!

Comparison with CERN's system (preliminary)

- Multiwavelength analysis
- Recovery: impact mid-range
- Readout refinement at mid and extremely high ranges



RIA at 630 nm as possible candidate to improve readout

First on-line RPL measurements!

A.Hasan, RADMEP Master Thesis (2023)

RPL samples (backup)

- **FD-7 glass rod**
- **Ag doped** phosphate glasses

CYLINDRICAL
1.5 mm diam x
8.5 mm length

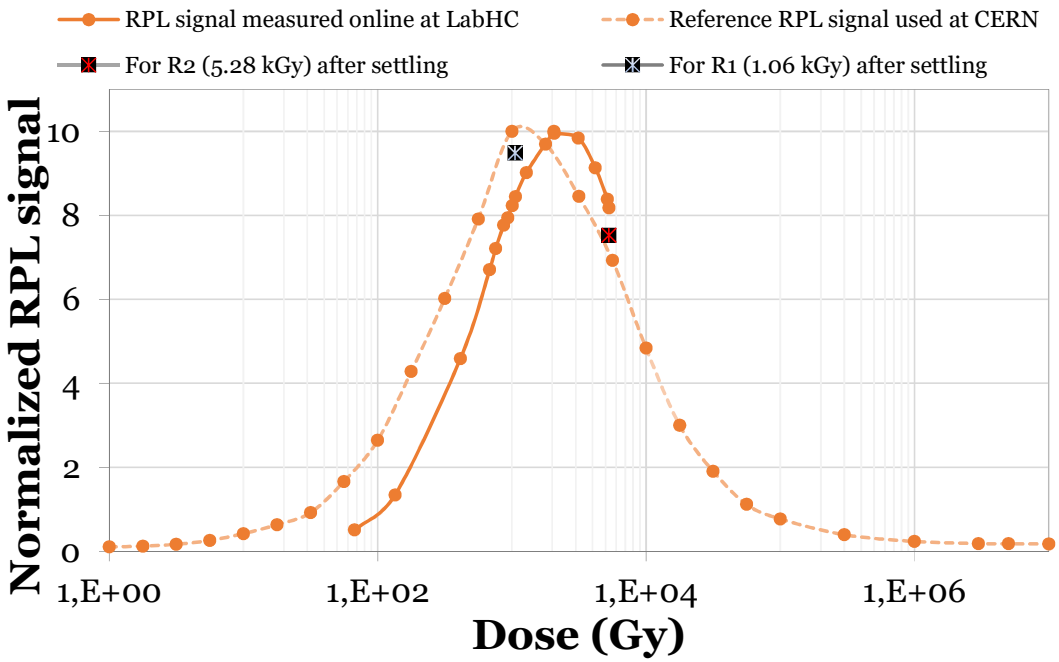
Features:

- **Linear RPL response with dose up to 10-500 Gy**
- Limited fading
- Non-destructive readout
- Reusable (after
- [illegible]ion)

	Density [g/cm^3]	O [wt-%]	P [wt-%]	Na [wt-%]	Al [wt-%]	Ag [wt-%]
FD7	2.6041	51.16	31.55	11.0	6.12	0.17

Used at CERN as a passive monitoring system in the MGy range (!)

On-line RPL signal (backup)



Samples:
R1: 1.06 kGy
R2: 5.28 kGy

Considering RPL signal after settling: both the passive measurement are almost same

A.Hasan, RADMEP Master Thesis (2023)

Experimental Activities

Dose dependency at constant dose rate

- 4 samples between 1.30 kGy and 0.47 MGy
- 3 samples between 1.05 kGy and 37.8 kGy
- 4 samples between 0.37 kGy and 5.10 kGy

Dose rate dependency

- 4 samples ranging from 1.75 Gy/s to 0.175 Gy/s
- 2 samples ranging from 1.036 Gy/s to 0.207 Gy/s

30 days long irradiation:

- 5 samples between 0.63 MGy to 2.81 MGy

RPL measurement:

- 2 samples in mid-dose range

Post-mortem:

- 4 samples, up to 2 months after irradiation

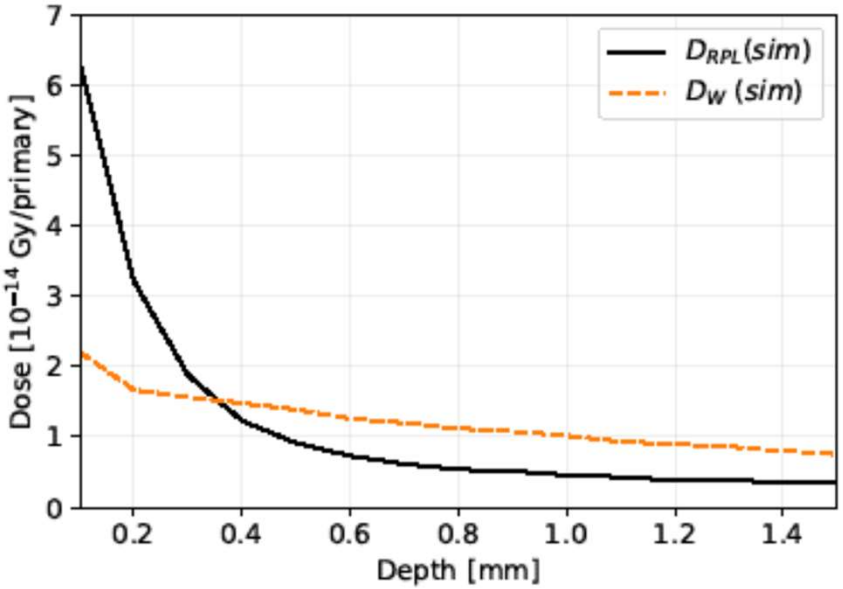
Confocal microscopy

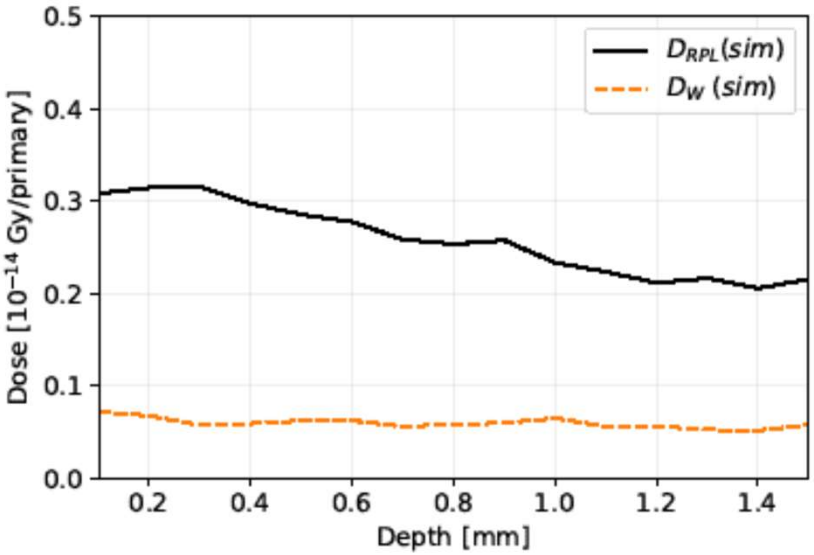
- 2 samples

39 irradiated samples
50 irradiation days

Selection of results

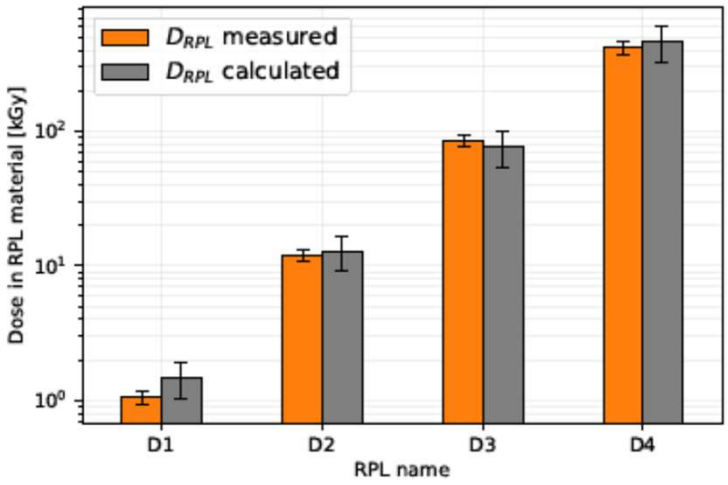
Dosimetry (backup slide)

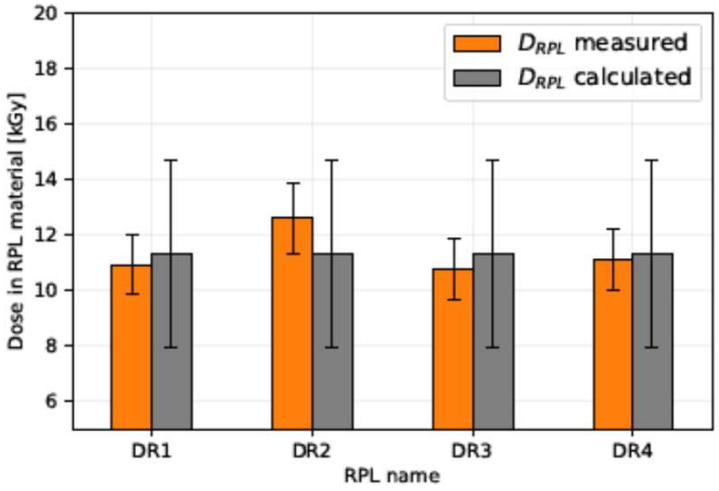




M. Ferrari, et al., Characterization of Radio-Photo-Luminescence dosimeters under X-ray irradiation, accepted to RADECS 2023 Conference on Radiation and its effects on Components and Systems, in preparation for submission to IEEE TNS, Sept 2023

CERN's readout (backup slide)





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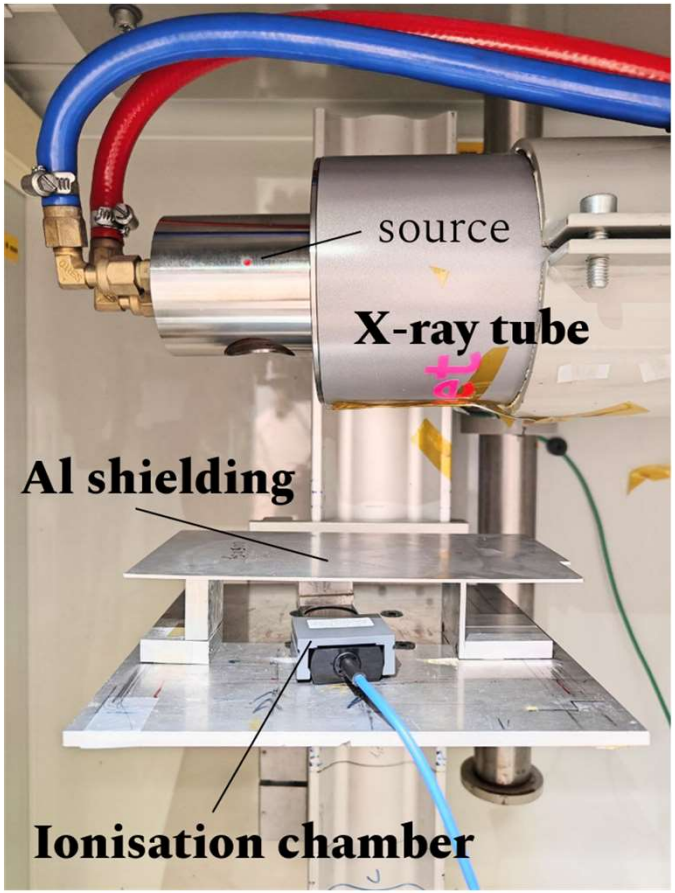
Calibration (backup slide)

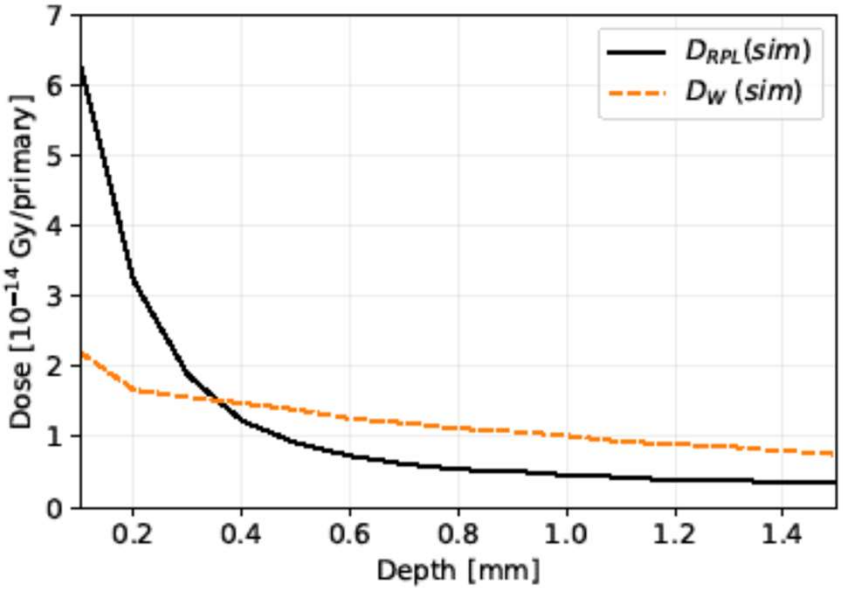


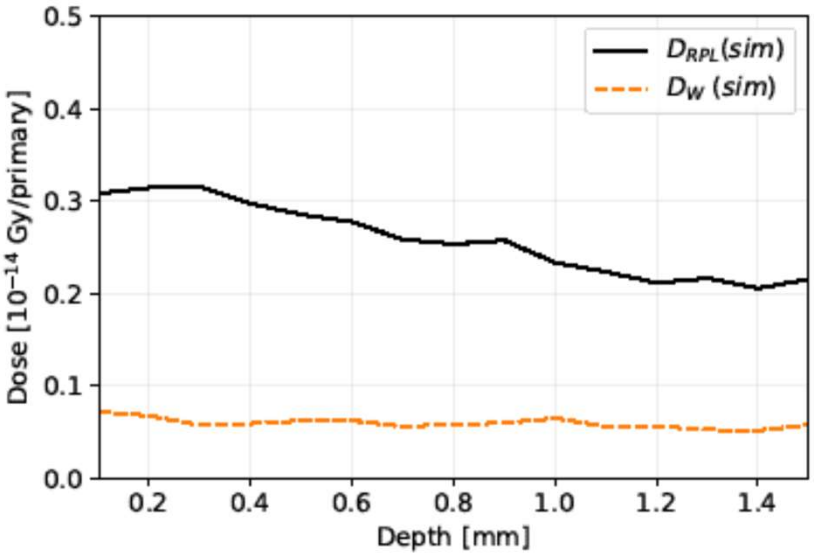
Gy [H_2O]/s × 3.7 → Dose rate in RPL material → **Gy /s × time** → Dose

**PTW-23344 0.23 cm3 Soft X-ray Chamber Datasheet.*

M. Ferrari, et al., Characterization of Radio-Photo-Luminescence dosimeters under X-ray irradiation, accepted to RADECS 2023 Conference on Radiation and its effects on Components and Systems, in preparation for submission to IEEE TNS, Sept 2023

Dosimetry (backup slide)





M. Ferrari, et al., Characterization of Radio-Photo-Luminescence dosimeters under X-ray irradiation, accepted to RADECS 2023 Conference on Radiation and its effects on Components and Systems, in preparation for submission to IEEE TNS, Sept 2023

Possible effect in dose estimation in mid-dose range

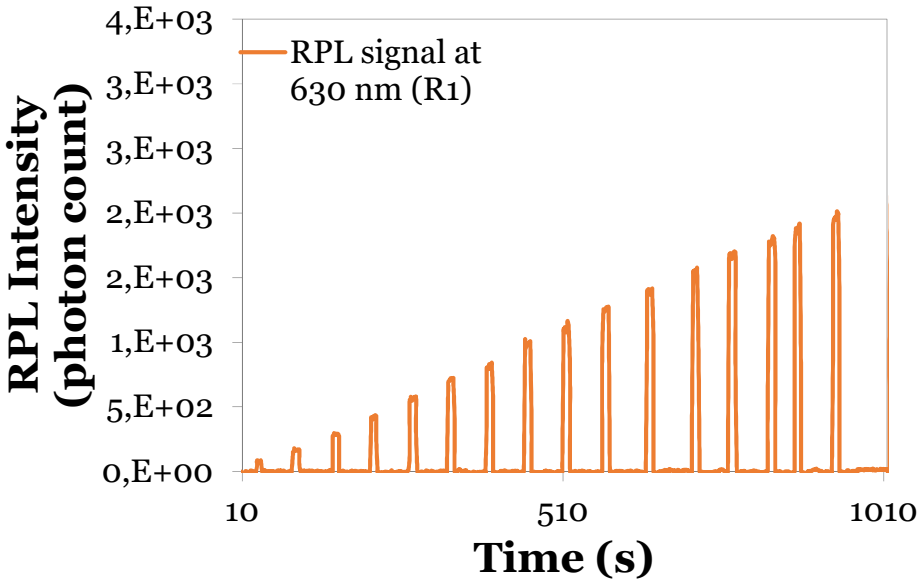
Sample Name	Dose Rate (Gy/s)	Actual Dose (kGy)	Dose Measurement 1 At CERN (kGy)	Ratio	Dose Measurement 2 At CERN (kGy)	Ratio
D1	2.159	1.30	1.0	0.77	0.98	0.75
D2	2.159	12.91	12	0.93		
D3	2.159	77.72	85.19	1.11		
D4	2.159	466	416.9	0.89		
DR1	1.75	11.34	10.9	0.96		
DR2	0.699	11.34	12.6	1.11		
DR3	0.35	11.34	10.7	0.95		
DR4	0.0175	11.34	11.1	0.98		
DR4.1	0.0175	1.05	0.94	0.90	0.83	0.79
DR4.2	0.0175	37.8	36.83	0.97		

Sample Name	Dose Rate (Gy/s)	Actual Dose (kGy)	Dose Measurement (kGy)	Ratio
M11	1.036	0.37	0.32	0.86
M21	1.036	1.06	0.79	0.75
M22	0.2072	1.06	0.82	0.77
M31	1.036	3.11	2.27	0.73
M32	0.2072	3.11	2.3	0.73
M41	1.036	5.1	4.46	0.87

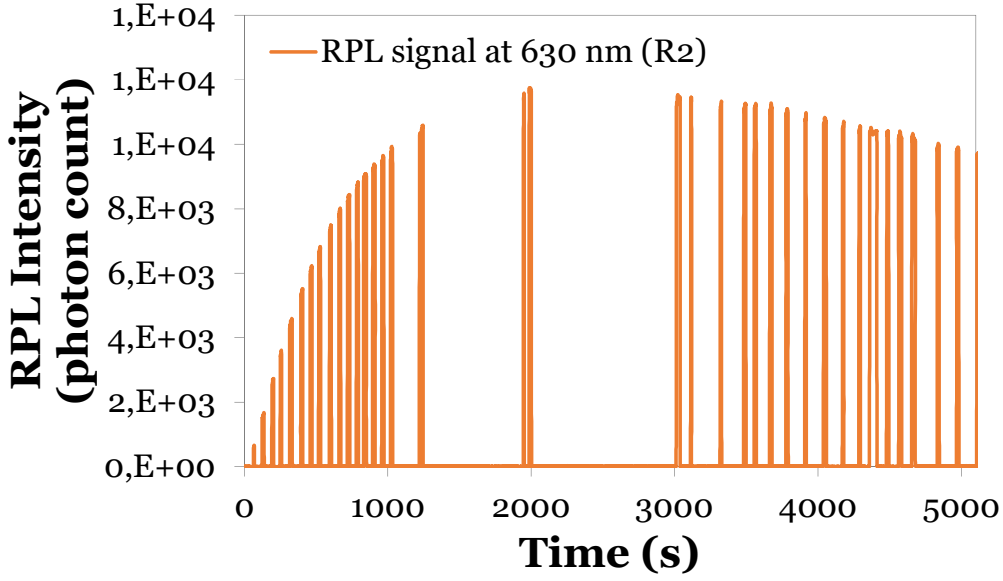
Sample Name	Dose Rate (kGy/h)	Actual Dose (MGy)	Dose Measurement (MGy)	Ratio
EST	3.4632	2.81	0.89	0.32

RPL signal during irradiation and settling after irradiation

R1: 1.06 kGy at 1.036 Gy/s



R2: 5.28 kGy at 1.036 Gy/s



- Readout of R1 sample after 14 hours: RPL settles to a **13% higher** photon count
- Readout of R2 sample after 12 hours**:** RPL settles to a **9% lower** photon count