Radioluminescent Optical fibre: Recent developments for dosimetry applications

R2E 2022 Annual meeting – Presented by Nourdine KERBOUB - CERN (EN-EL-FO) / CNES / UJM

Diego Di Francesca (EN-EL-FO), Daniel Ricci (EN-EL-FO)

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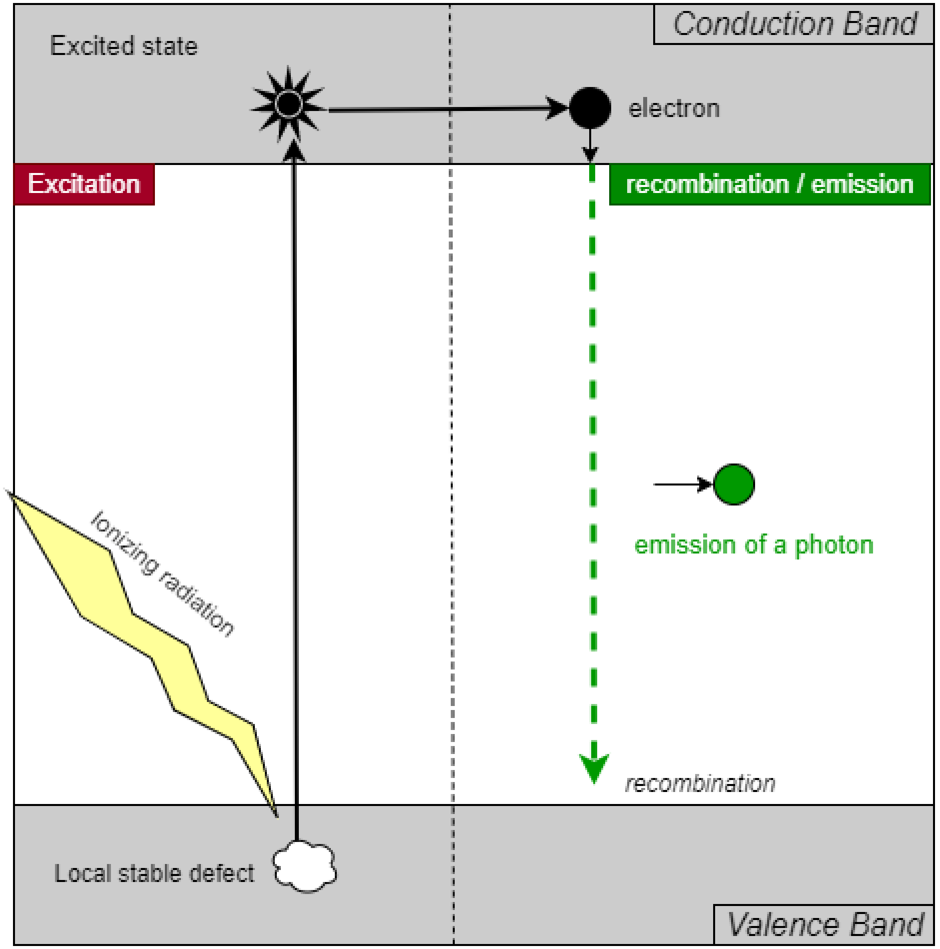
https://indico.cern.ch/event/1116677/contributions/4695308/

Agenda

1. Introduction
2. Experimental setup
3. Effect of pre-irradiation on the radioluminescent response
4. Temperature effects on pristine and pre-irradiated radioluminescencent optical fibre response
5. Conclusion

Introduction to Radioluminescence (RL)

Simplified radioluminescence process



- The radioluminescence process takes place when an ionizing particle excites a local defect in the material.
- The local defect enter in an excited state.
- Within a short decay time (ns to ms), the defect recombines to return into a stable state, via the emission of a photon.
- This process can be created or enhanced by adding special dopants to the material.

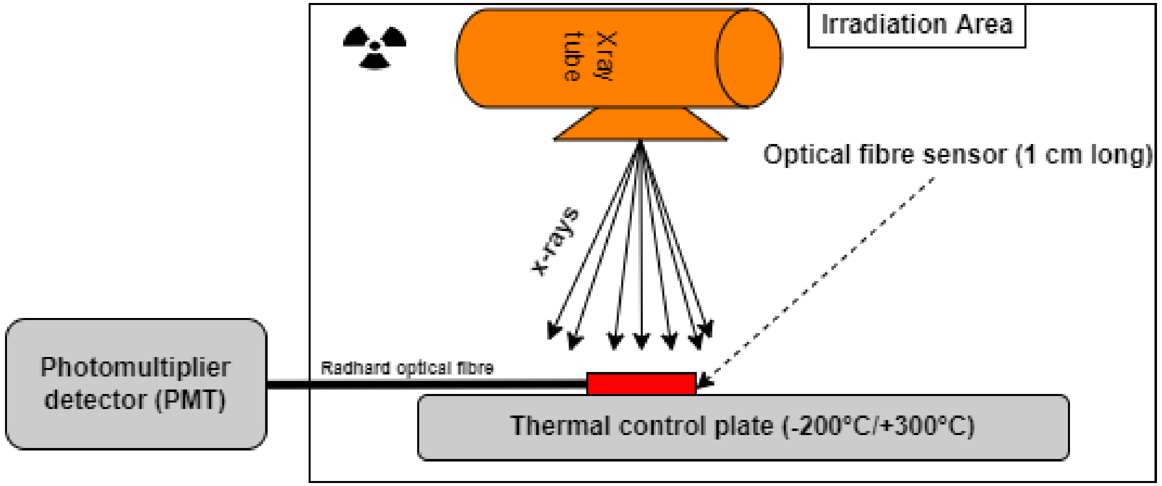
Environments of interest for our project

Accelerators
Dose range : Up to 1 MGy
Dose rate range : Up to 10^{-1} Gy.s^{-1}
Temperature range : Mostly room Temperature (RT)

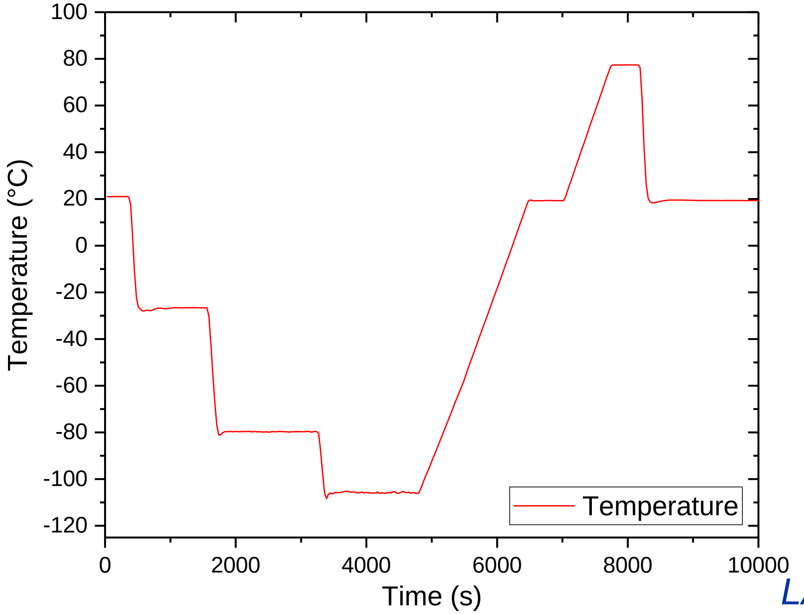
Space
Dose range :Up to 5 kGy, usually within 100-500 Gy
Dose rate range : 10^{-9} to 10^{-7} Gy.s^{-1}
Temperature range : -200°C to 300°C

S. Girard et al., J. Opt. 20 (2018) 093001 (48pp)

Experimental setup : Temperature effects



- Typical temperature steps applied during the experiment.
- We perform a RL measurement at every stabilized temperature.

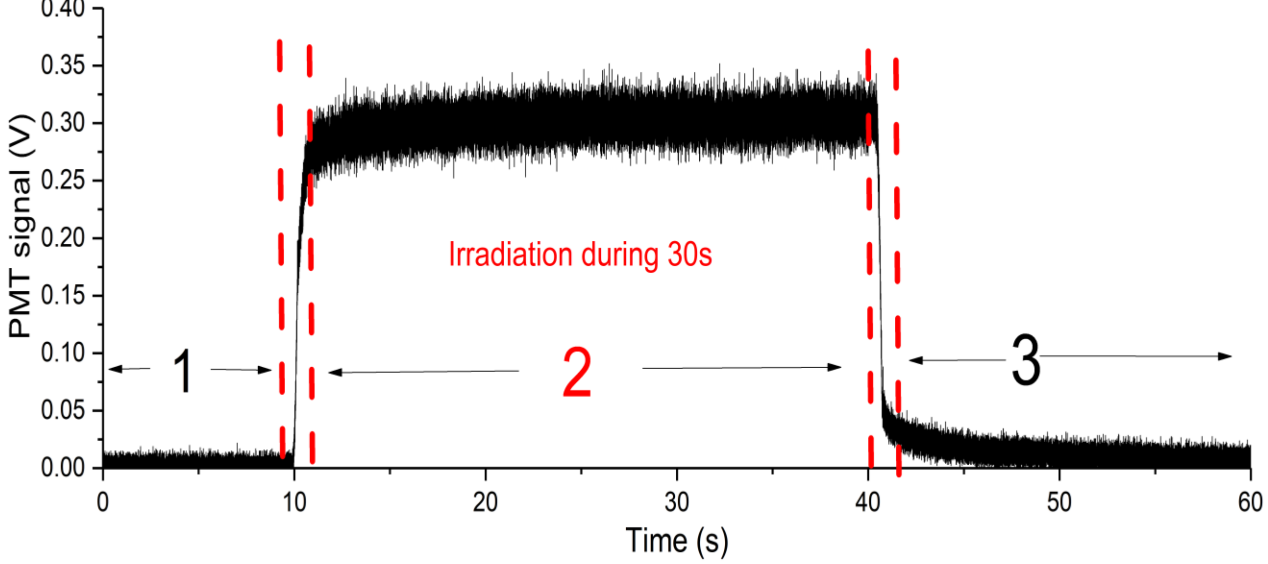


LABHX irradiation machine at LabHC, Saint-Etienne, France

Method of the RL measurement

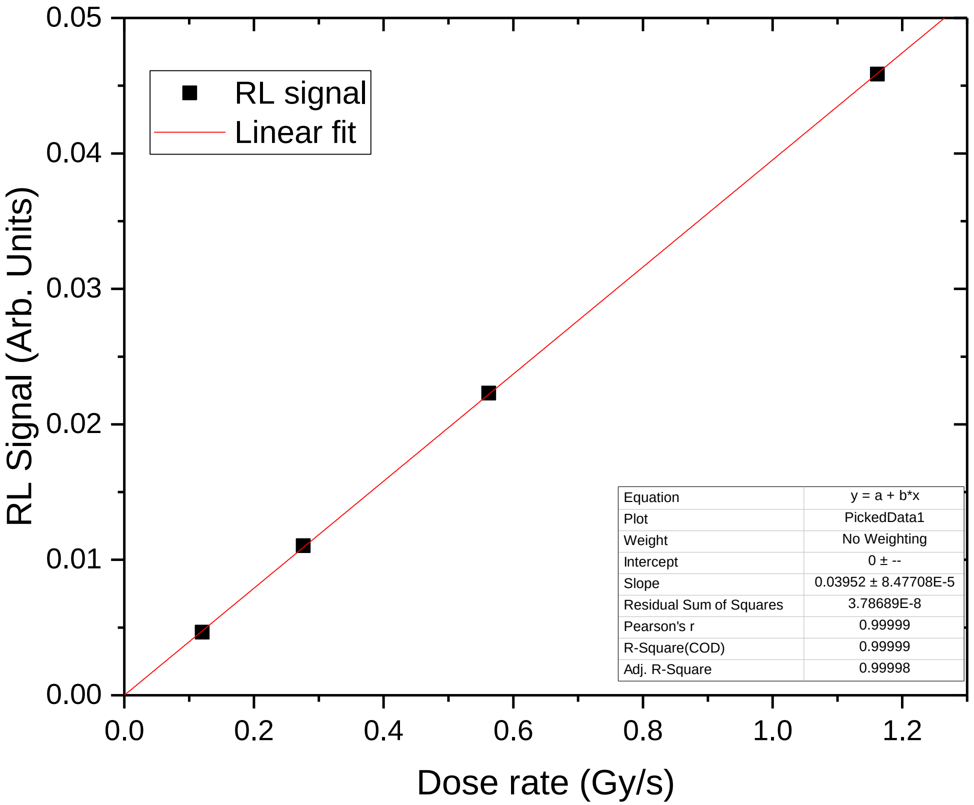
1 – Before Irradiation
2 – During irradiation
3 – After irradiation

RL Response = Mean(2) –Mean (1)

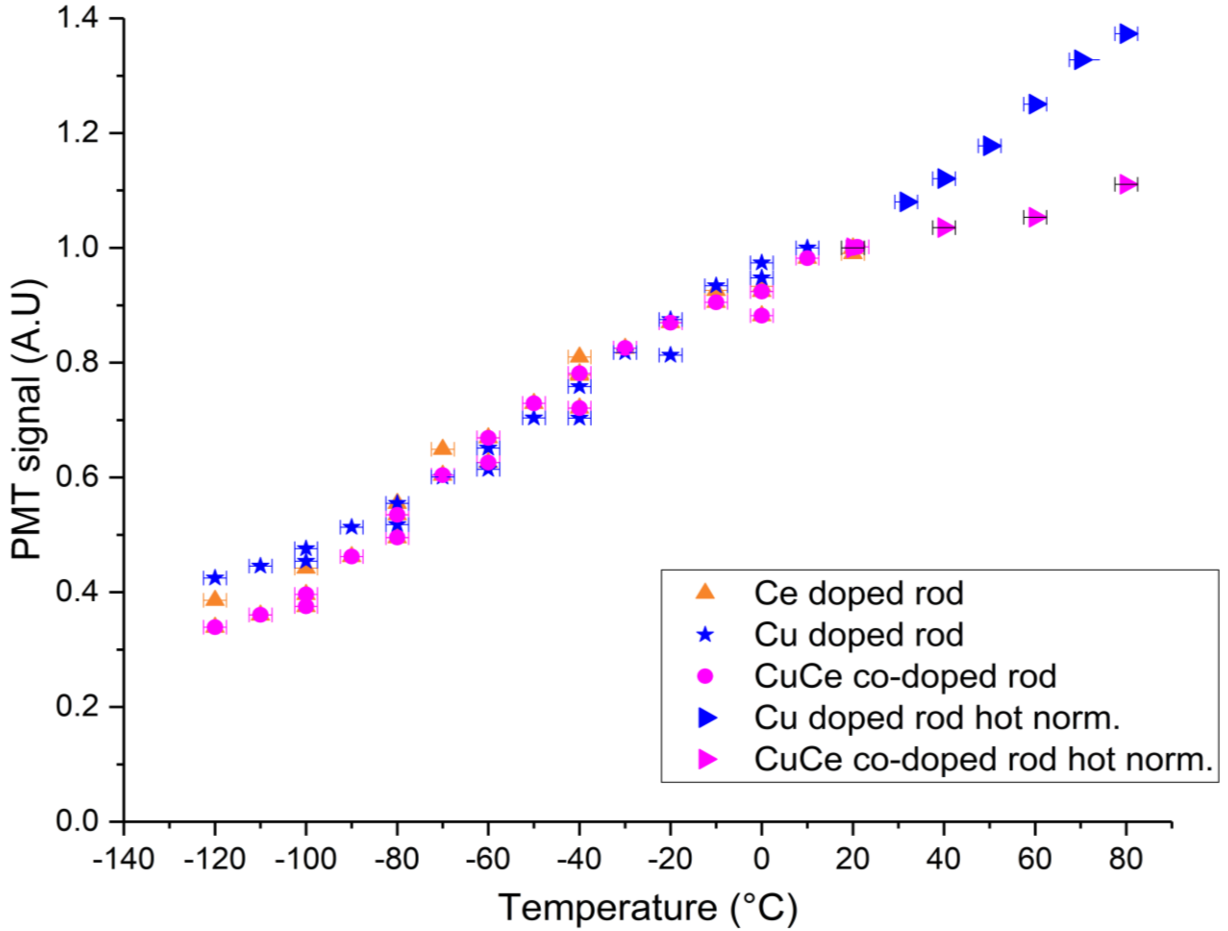


Typical Radioluminescence measurement

The RL response is proportional to the ***dose rate***, and linear for the best sensors.



Previous results – RL signal *vs* T° on optical fibre material (rods)



- RL response of Ce-, Cu- doped and CuCe co-doped materials vs temperature.
- Significant temperature dependence over the investigated temperature range.
- More recently, 125 µm diameter fibres have been drawn from these optical fibre material.

Is the RL temperature dependance on these fibres similar to that observed in the material?

- In this presentation we present the result of the temperature effect on both **pristine and pre-irradiated fibres**.

N. Kerboub *et al.*, "Temperature Effect on the Radioluminescence of Cu-, Ce-, and CuCe-Doped Silica-Based Fiber Materials," in *IEEE Transactions on Nuclear Science*, vol. 68, no. 8, pp. 1782-1787, Aug. 2021, doi: 10.1109/TNS.2021.3075481.

Evolution of the RL signal with dose – 1 cm long sample at 20 Gy/s

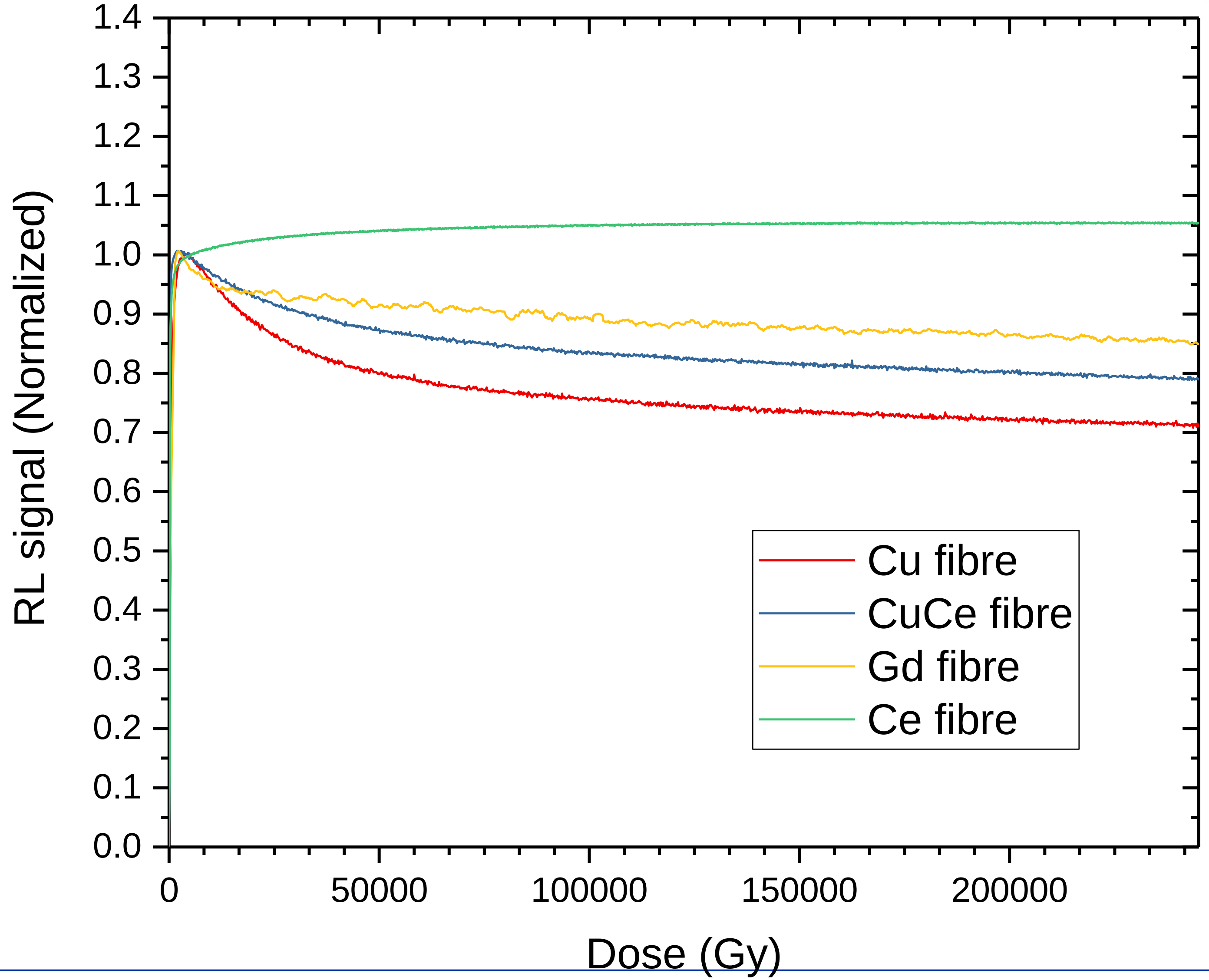
We have performed a dose effect study on the optical fibres investigated in this work.

For this purpose, we have submitted a 1 cm long sample of each type to a 20 Gy/s X-ray irradiation while monitoring the RL emitted signal, up to a dose of 250 kGy with a spectrometer.

In the figure presented here, we have plotted one wavelength, at the center of the emission band of each sample.

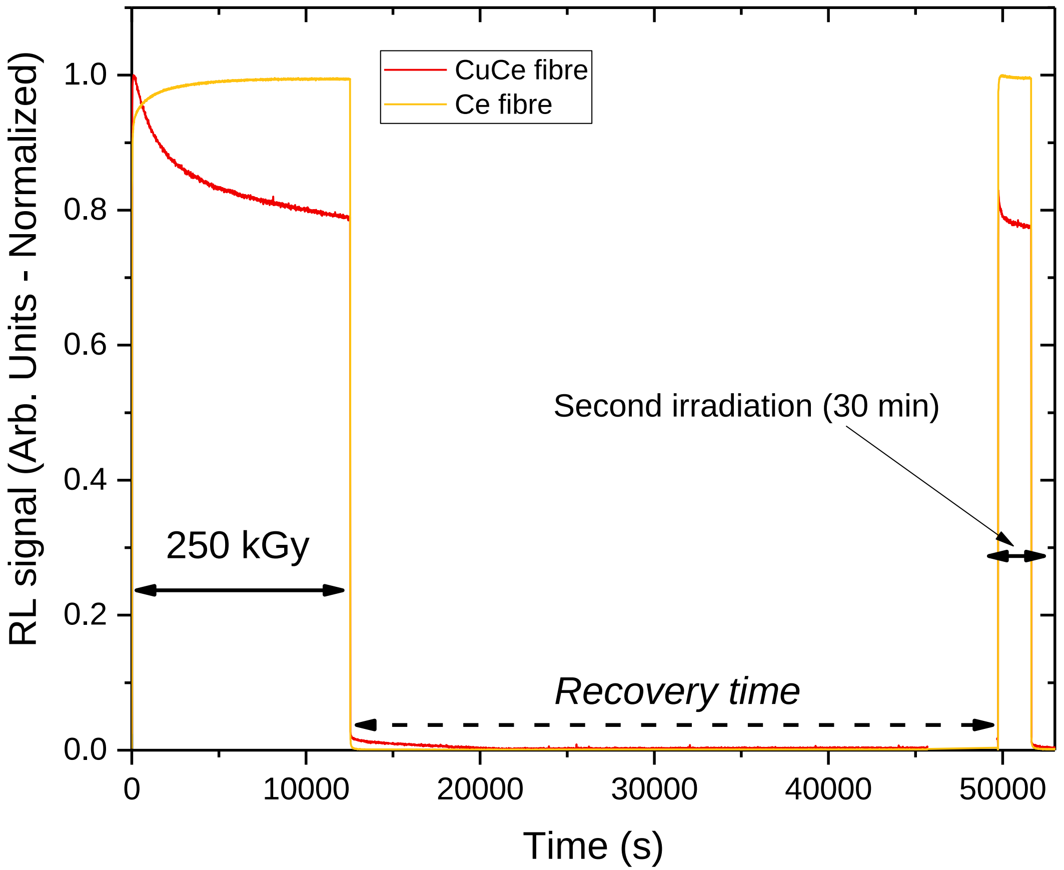
The result shows that :

- **The RL signal changes with the deposited dose.**
- **A pre-irradiation might be needed before use in order to stabilize the signal.**

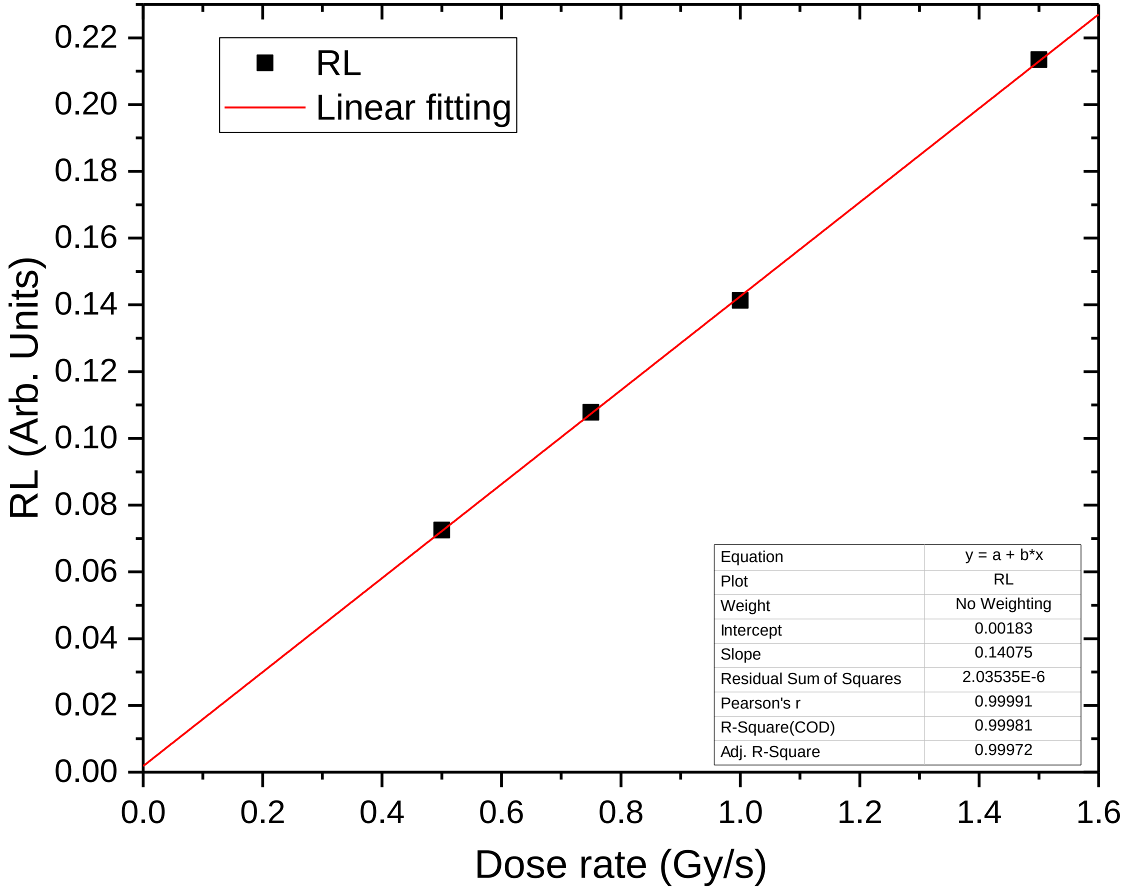


Second irradiation – Properties maintained after recovery time

Experiment performed on 1 cm long samples at 20Gy/s



The RL signal returns to a similar level after a recovery time.



The RL response remains linear after pre-irradiation to 250 kGy level

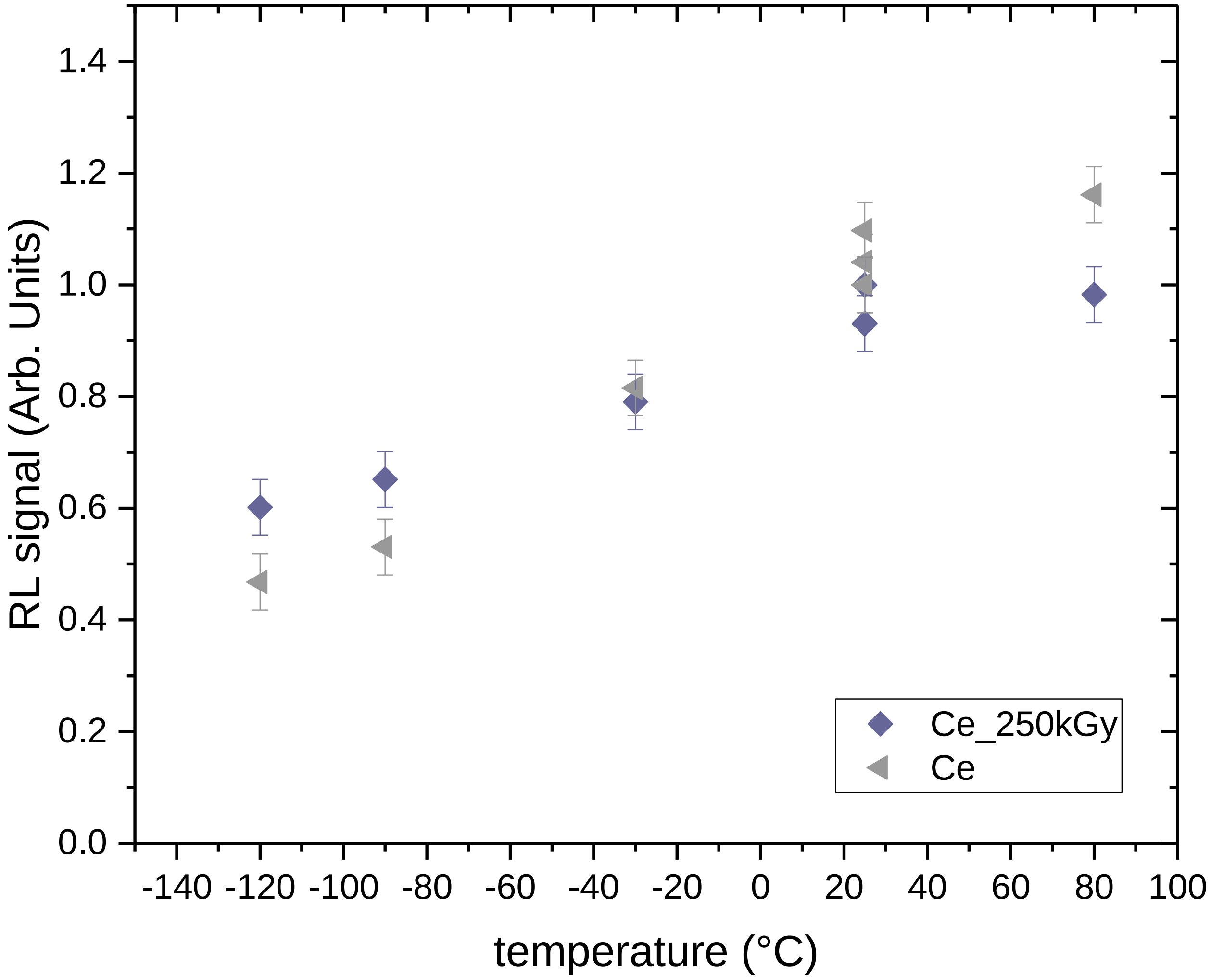
Ce-doped fibre – Pristine vs Pre-irradiated

- **Ce-doped sample**
- The temperature dependence in pristine samples is similar with that observed in rods (within 10%)
- The pre-irradiation of the fibre seems to reduce the temperature dependence of the RL.

Slope of the temperature dependence

Ce pristine fibre → Pre-irradiated fibre

- 45%



Cu-doped fibre – Pristine vs Pre-irradiated

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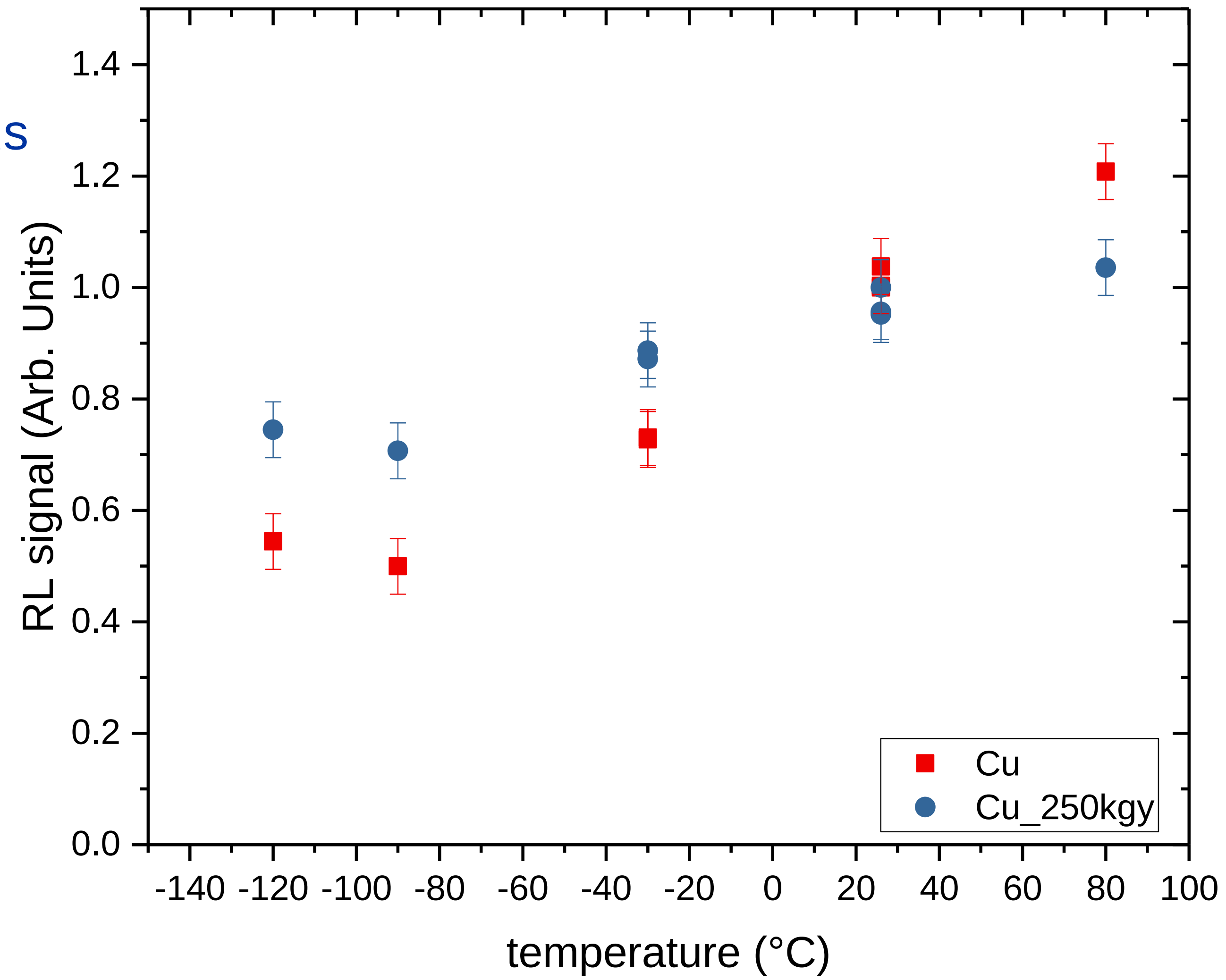
Cu-doped sample

- The temperature dependence in pristine samples is similar with that observed in rods (within 20%).
- The pre-irradiation of the fibre seems to reduce the temperature dependence of the RL.

Slope of the temperature dependence

Ce pristine fibre → Pre-irradiated fibre

- 60%



CuCe-doped fibre – Pristine vs Pre-irradiated

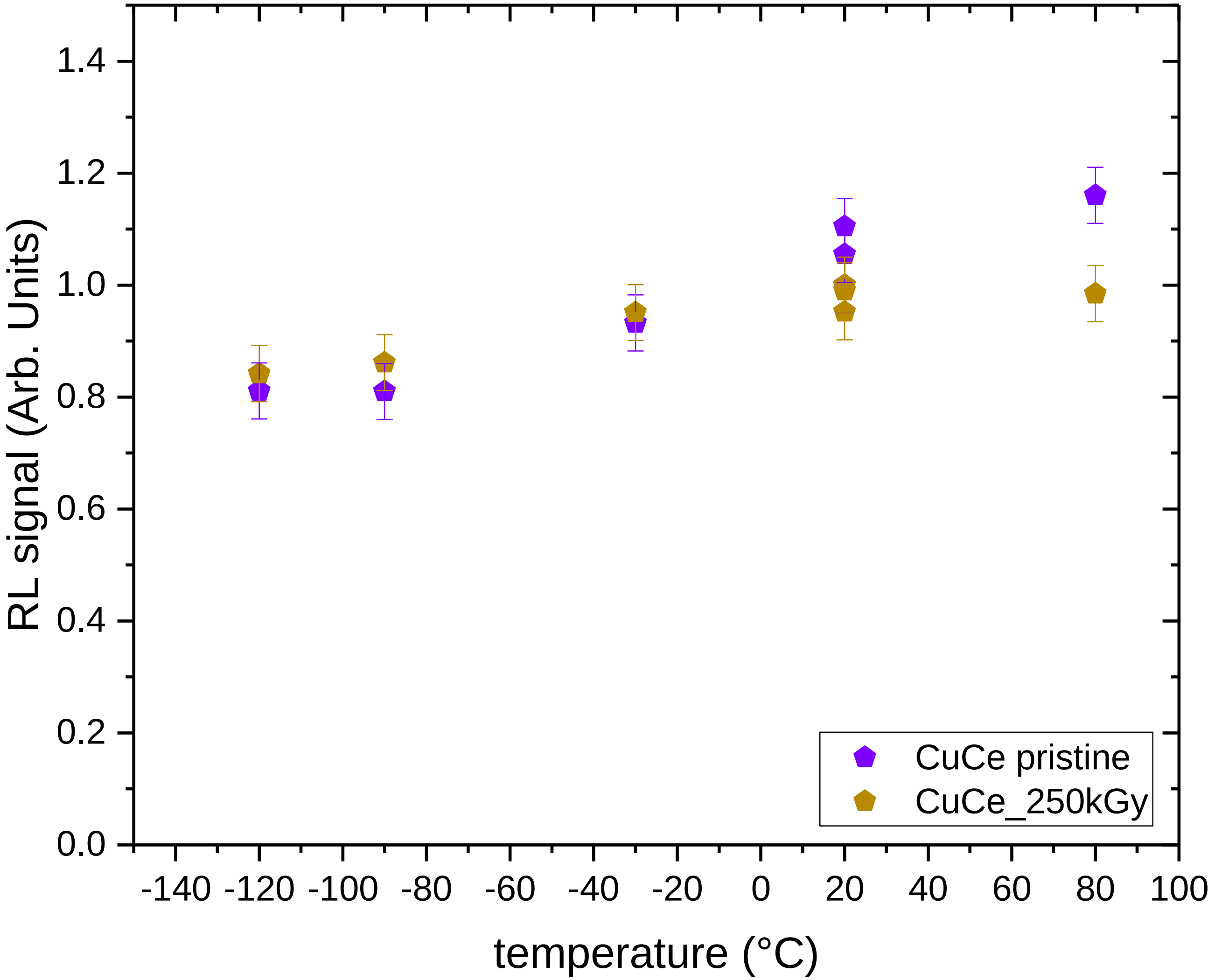
CuCe-doped sample

- The temperature dependence in pristine samples is **more important** than that observed in rods (+50%).
- The pre-irradiation of the fibre seems to reduce the temperature dependence of the RL.

Slope of the temperature dependence

Ce pristine fibre → Pre-irradiated fibre

- 60%



Gd-doped fibre – Pristine vs Pre-irradiated

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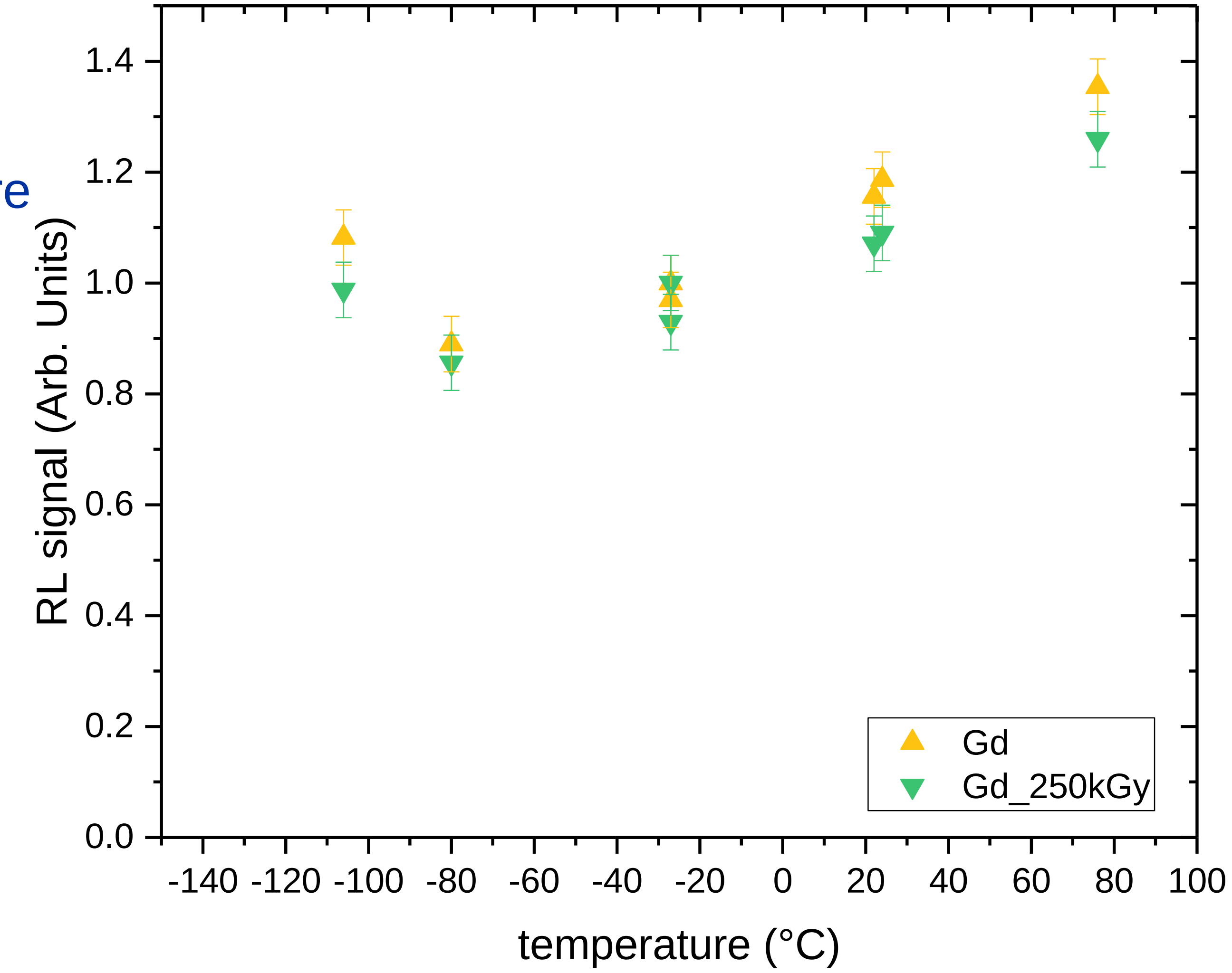
Gd-doped sample

- The pre-irradiation of the fibre seems **not** to have an important impact on the temperature dependence of the RL.



Conclusion

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- The temperature dependence on the RL signal of the Ce, Cu doped and CuCe co-doped optical fibre tested in this study are relatively similar (within respectively 10, 20% and 50%) with that observed in the optical material they are drawn from.
- **Pre-irradiation seems needed** before using these fibres for dosimetry application, in order to stabilize the RL response.
- The temperature dependence of the Ce, Cu or CuCe doped or co-doped samples is reduced by the pre-irradiation (**45 to 60% reduction wrt pristine fibre**). That of the Gd doped fibre seems not to be affected significantly by the pre-irradiation.

- On an application point of view we can say the best sensor choice would be between the Ce and Cu-doped fibres , **depending on the environment conditions.**
- The calibration of such sensors should be carried out after the pre-irradiation of the samples.
- In certain type of environments, it could be decided not to use temperature calibration/correction if the temperature variations are limited around the ambient temperature.

Outlook

We are at the moment, performing a systematic coupled study of the RL signal and RIA measurements, for different lengths of differently doped fibre.

This data is interesting to :

- Understand better the RIA mechanism occurring in these fibre sensors.
- Understand better how the RIA plays a role in the RL signal variation with increasing TID.
- In the end, the main application-oriented objective is **to identify the optimum length of fibre**, providing the best **trade-off between RL and RIA** .

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