



Potential of radioluminescent silica-based optical fibers for 14 MeV neutron beam monitoring[☆]

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ABSTRACT

The present paper proposes a solution for 14 MeV neutron beam monitoring employing Ce-doped optical fibers, based on the radiation-induced luminescence (RIL) phenomenon. Context is given on the possible use of these fiber-based monitors in fusion experiments, exploiting the advantages of optical fibers and of the proposed setup to overcome the limitations given by the harsh environments of fusion-related facilities. Here, the advantages of optical fibers (size, weight, electromagnetic immunity, among others) are complemented by the possibility of a very simple single-ended setup, which can be operated remotely, avoiding the exposure of the detectors to radiation. Two 2-cm long Ce-optical fibers were tested, one pristine and one that was X-ray pre-irradiated at 250 kGy(SiO₂). The investigated optical fibers have been characterized at the Frascati Neutron Generator (FNG) of ENEA (Italy) under 14 MeV neutrons and a flux varying between 4×10^7 and 4.5×10^8 n cm⁻² s⁻¹. Two runs have been performed, a first one to calibrate the RIL response to the neutron flux, via a linear fit between the facility monitors and the optical fiber response. A second run was then performed to validate the calculated sensitivity. The positive effect of pre-irradiation is demonstrated by a clear improvement in RIL response. The final results show a maximum deviation in the fluence measurements from the alpha counter of the facility of 6 % for the pristine fiber and 4 % for the pre-irradiated one, both values are lower than the 7 % deviation between the alpha counter and the fission chamber of the FNG facility.

1. Introduction

For decades, researchers have dedicated efforts to replicate the self-sustaining stellar fusion rate in a quest to obtain a nearly limitless source of low-carbon and clean energy. In stars, the gravitational forces provide the natural conditions necessary for fusion. The fundamental obstacle to realize a fusion energy source remains the difficulty in controlling, heating and confining the plasma at the conditions required for ignition, together with maintaining these conditions for a sufficiently long time so that more energy is produced than what was supplied to initiate the

fusion reaction. Two main approaches are investigated worldwide to overcome this obstacle: magnetic confinement and inertial confinement. Fusion reaction via magnetic confinement refers to tokamaks (e.g. the Joint European Torus (JET) in the UK (JET Team (Prepared B. M. L. Watkins), 1999) and ITER in France (Shimomura et al., 1999) and stellarators (e.g. W7-X in Germany (Klinger, 2019) where superconducting magnets are used to confine the plasma in a controlled environment. Fusion via inertial confinement is, instead, based on indirect drive implosion: the idea is to employ Megajoule-class lasers (e.g. Laser Megajoule (LMJ) in France (Bourgade, 2008) and National

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Ignition Facility (NIF) in the USA (Abu-Shawareb, 2022) focused on a miniaturized cryogenic target to confine the reaction inside a gold hohlraum through the X-rays that are generated on impact by the extremely intense lasers (Abu-Shawareb, 2022; Abu-Shawareb, 2024). The environments surrounding these conditions are inherently harsh, as they combine high radiation constraints (a combination of X-rays, γ -rays and 14 MeV neutrons) with other phenomena: strong magnetic fields (up to 6 T) and high temperatures (up to 1000 °C on the plasma facing components) for magnetic confinement reactors (Deparis, 1998) and the shock, ablation and shrapnel resulting from the implosion of the mixture inside the hohlraum where the MJ-class lasers are focused, among others (Bourgade, 2008; Bourgade, 2004; Bourgade, 2014). The fusion reaction at the core of both technologies is Deuterium – Tritium (DT). Each DT reaction results in the release of one energetic helium, also known as an alpha particle (at 3.5 MeV), and one even more energetic 14 MeV neutron (Abu-Shawareb, 2024). In both technologies, the alpha particle will be confined near the reaction volume due to the magnetic fields around the plasma in magnetic confinement and to the compressed core shell in MJ-class lasers (Bourgade, 2004). The energy of the alpha particle is then used to self-sustain the burning plasma; while that of the neutrons is ultimately the main output of the reaction. These high-penetrative and non-charged neutrons will reach the external parts of the reaction areas, affecting materials, instruments and even people, if not properly handled (Radiation Research, 2001; IAEA, 2023). An important challenge of the construction of these facilities is then the monitoring and mapping of these 14 MeV neutrons, so as to know the radiation levels that the installed components will have to withstand, and, even more importantly, to monitor the fusion products to estimate the fusion output power (Bourgade, 2008; Bourgade, 2004; Bourgade, 2014; Bertalot, 2019; Giacomelli, 2005; Vitaly Krasilnikov, 2024). For ITER, the expected total neutron flux is between 10^{14} and 7.5×10^{20} n s⁻¹ over 4 π steradians in the whole irradiation area (Bertalot, 2019). This corresponds to a directional flux at 5 m from the plasma source going from 3.2×10^7 to 2.4×10^{14} n cm⁻² s⁻¹. In MJ-class lasers, once a $\times 10$ gain shot is achieved, 10^{19} neutrons in all directions are expected for each shot over a duration of ~ 150 ps (Bourgade, 2004; Bourgade, 2014). In the most recent ignition shot at the NIF, in December 5, 2022 when scientific breakeven was achieved with 2.05 MJ of 351 nm laser light producing 3.1 MJ of total fusion yield, obtaining a target gain surpassing unity (Abu-Shawareb, 2024; Di Nicola, et al., 2024). The estimated neutron yield for this shot was around 5×10^{18} n over 4 π steradians. This corresponds to a neutron fluence at 5 m from the implosion of 1.6×10^{12} n cm⁻² for a single shot. The challenging environments adorning the two technologies of fusion reactor are pushing the research for new sensing solutions that should be able to withstand these constraints while obtaining reliable measurements. Optical fibers have a number of advantages compared to electronic-based sensors that can be very appealing for these technologies. They are lightweight, small and immune to electromagnetic fields, a clear requirement to work with magnetic confinement fusion reactors due to the strong magnetic fields involved, and with inertial confinement ones to resist the electromagnetic pulse that accompanies the implosion shots (Min et al., 2021). They can then be engineered to sustain high amounts of radiation and temperature, and can be easily deployed for remote sensing, so that the most delicate components can be placed outside said harsh environment. As a proof of that, purposely-designed optical fibers have been already implemented in both magnetic and inertial confinement for data transmission as well as magnetic fields, plasma and laser diagnostics (Deparis, 1998; Bourgade, 2014; Gusarov et al., 2018; Girard, 2012). The approach proposed in this work is based on optical fibers that have been functionalized to react to radiation mainly through the radiation-induced luminescence (RIL) phenomenon. RIL is the spontaneous emission resulting from the relaxation of pre-existing or radiation-induced intra-band traps inside the optical fiber. It can be optimized through the choice of dopants introduced in the glass matrix. The result is a radiation flux-dependent light emission from the fiber that can be

easily guided outside the irradiation zone through a transport fiber and collected with a light detector. The simplicity of this single-ended setup is one of the main selling points of this solution, together with the small size of the fibers. Usually, the external diameter of the guiding structure of an optical fiber is 125 μ m, composed of core and cladding. A coating layer is then added, ranging from 250 μ m to some mm of diameter, to improve the fiber mechanical properties (Li, 2020). In most applications, few centimeters of sensitive fiber have been shown to be the optimal length for a RIL-based detection system, as longer samples would have to consider for the effect of intrinsic and radiation-induced attenuation of the sample under test (Girard, 2018; Kerboub, 2023). The setup is also inherently remotely operated, meaning that the exposition of the light detector to radiation or other constraints of the aforementioned harsh environments are of no concern, as it can be placed outside the exposed zones, even if tens of meters away. Across multiple works, these radioluminescent fibers have been put to the test in radiation environments and cases thanks to their linear response to particle flux (dose rate) and low sensitivity to cumulative fluence (dose) (Girard, 2017; Veronese, 2010; Fricano, 2023). Their RIL responses were shown to be linear with dose rate across multiple decades under X-rays (Vidalot, 2022) and they do not lose their detection capabilities even after being exposed to high fluences/doses. Indeed, a pre-irradiation treatment from hundreds of kGy to MGy of dose has been demonstrated to stabilize and improve the reliability of the measurement (Kerboub, 2023; Fricano, 2024). After the treatment, the sensitivity can increase while parasitic behaviors are reduced. Among these are the after-glow, a luminescence occurring after the irradiation end, thought to be related to the slow relaxation of deep traps, and the bright-burn effect, a cumulative increase with received dose in the sensitivity of the RIL fiber, which could be explained by the disappearance (or filling up) of deep traps which compete with the recombination centers related to RIL during irradiation (Fricano, 2024). The reduction thanks to the pre-irradiation of the impact of these deep traps explains the increase of the radioluminescence sensitivity. As the number of those traps, that compete with recombination centers at the basis of the RIL, strongly decreases with the pre-irradiation dose, the luminescence signal for a same dose rate increases for the pre-irradiated sample with respect to the pristine one. In addition to these phenomena, one should take care of the stem effects, which include Cherenkov light and other kinds of parasitic luminescence from the sensitive or transport fibers when they are crossed by a particle, which can introduce an error in the measurement. There exists then a clear interest in testing the promises of RIL-based detectors under 14 MeV neutrons, to propose a solution capable of characterizing the extreme environment and the reaction output in fusion experiments. In this paper, the 14 MeV neutron generator at the Frascati Neutron Generator facility of ENEA in Frascati (Italy) (Pietropaolo, 2018; Martone et al., 1994) has been used to evaluate the capability of two samples (pristine and pre-irradiated) of the Ce-doped silica optical fibers to measure the neutron flux and fluence over time.

2. Materials and methods

2.1. The Frascati neutron generator

In this work, two optical fibers have been tested at room temperature and calibrated to quantify the flux and fluence of 14 MeV neutrons at the Frascati Neutron Generator (Pietropaolo, 2018; Martone et al., 1994). This is a facility built to generate 14 MeV neutrons thanks to an accelerated deuteron beam impinging on a tritiated target. At nominal operating conditions (300 keV–1 mA), the result is a neutron yield up to 10^{11} n s⁻¹ that can be used both to test the radiation hardness of electronic devices or, like in the case of this work, to test neutron detectors. Fig. 1 shows the schematic of the experimental setup. The facility provided a spatial mapping of the area in front of the tritium target in terms of neutron flux and fluence. The samples were placed 1 cm away from the tritiated target, on the beam axis.

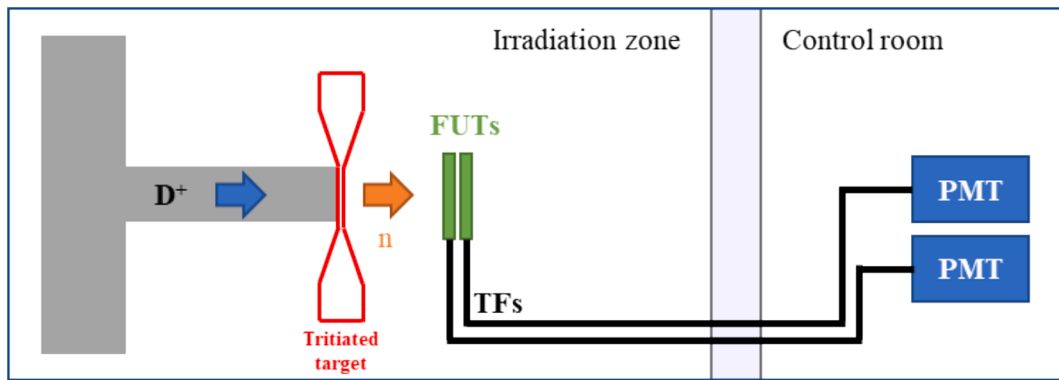


Fig. 1. Out-of-scale schematic of the irradiation and RIL measuring setup. From the left in order: the deuterons accelerator (gray), the tritiated target (red), the two fibers under test (FUTs) (green), the two transport fibers (TFs) (black), and the two PMTs (blue), in the control room after the concrete wall. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.1.1. Alpha counter

The accelerated deuteron hitting the tritium target results in the release of a 3.5 MeV alpha particle and a 14 MeV neutron. One solution to quantify the neutron yield of the reaction is then to count the number of alpha particles released. For each irradiation run, the results of the alpha counter gave information about the total neutron yield at each second. This is the reference neutron counter of the facility, as it provides the most accurate reading of the neutron flux and fluence using a proper calibration factor.

2.1.2. Fission chamber

For redundancy, the facility provides a second reading of the total neutron yield, based on U-235 or U-238 fission chambers placed behind the tritiated target. A fission chamber converts neutrons into charged particles after having interacted with a fissile deposit coating the chamber anode and/or cathode. The collection of the charged particles is then performed via polarization of the ionization of the gas-filled chamber to estimate the total neutron yield of the DT reaction.

2.2. Ce-doped optical fibers

Two samples, each 2-cm long, of the same optical fiber were used for this study. This optical fiber is composed of a 102 μm Ce-doped (0.16 %) core and a 125 μm pure silica cladding. To allow its splicing to the transport optical fiber, the polyimide coating of the fiber had been removed. One sample had never been irradiated before, and will be called 'Pristine' from now on. The second one was pre-irradiated to 250 kGy(SiO_2) under X-rays at 6 Gy(SiO_2)/s in the MoperiX irradiation facility at Université Jean Monnet (France), equipped with a 100 kV tube and a W target (Meyer et al., 2023). To avoid the influence of ambient light, each fiber was put inside its own closed thermal sleeve. The usage of these two samples will permit the evaluation of the parasitic effects in RIL fibers mentioned in the introduction under neutrons.

2.3. RIL measuring setup

The interrogation setup shown in Fig. 1 is composed of the two radioluminescent optical fibers (FUTs). To allow the connection between the irradiation zone and the control room, two identical 25 m radiation-hard pure-silica core optical fibers (112 μm core, medium OH sample described in (Campanella, 2021) were spliced to the samples to transport the generated light from the irradiation zone to the control room. In there, two Hamamatsu H7421-40 photomultiplier tubes (PMTs) (Hamamatsu, "Photon Counting Head H7421 Series." Accessed: Sep. 06, 2024) optimized around the Ce emission wavelength of 500 nm have been used to measure the amount of light emitted. In a previous measurement, the transport fibers (TFs) were put directly in the neutron

beam to evaluate for the parasitic stem effect in a worst-case configuration. This resulted in a very weak luminescent signal, $\sim 5\%$ of the signal seen with a Ce-doped optical fiber, which will be considered as negligible in the presented test configurations.

3. Results and discussions

3.1. Measured kinetics with the alpha counter and the fission chamber

In Fig. 2 are reported the kinetics of flux and fluence received by the fiber during the irradiation run, measured via the alpha counter and the fission chamber of the facility. The flux over time was controlled manually by the operator of the facility, without any specific irradiation pattern in mind, with the objective to evaluate the response of the fiber to random fluctuations. The green area reports a 28 s interruption of the neutron beam. The obtained flux varies from 4×10^7 to $4.5 \times 10^8 \text{ n cm}^{-2} \text{ s}^{-1}$, while the final fluence was $5.4 \times 10^{11} \text{ n cm}^{-2}$.

3.2. RIL kinetics

The RIL kinetics of the two Ce-doped optical fibers are reported in Fig. 3, while the raw responses are plotted in Fig. 3a. Note that in this figure, the zero on the x axis is at the start of the irradiation, this is because the signal before the 0-minutes mark is averaged to compute the PMT dark noise to be removed from the RIL estimation. This plot shows the variation over time of the RIL during the neutron exposure, where a series of steps can be recognized, without a defined sequence. The plots for the two fibers are clearly following the same trend, with the pre-irradiated fiber having a sensitivity around 2.5 times higher than the pristine one, in accordance with the literature. As mentioned in the introduction, the RIL sensitivity of this Ce-doped fiber increases with a pre-irradiation treatment (Kerboub, 2023). The integrated RIL shown in Fig. 3b shows, instead, the integral over time of the RIL signal, reported here to be compared with the fluence plots. As the integration time is one second, the RIL integral is simply calculated as the cumulative sum of the corrected RIL (after removing the noise) at each second. Accordingly, this plot shows the cumulative evolution of the RIL signal, where each of the (almost) linear sections corresponds to the steps visible in Fig. 3a. The similitudes between these plots and the references obtained with the instruments of the facility in Fig. 2 are evident. The kinetics follow the neutron flux to which the fiber is exposed, with different sensitivities between the two fibers and lower fluctuations overall. The short irradiation interruption highlighted by the green area is also visible on the fiber kinetics. During this period, a slight after-glow phenomenon can be observed, where a fraction of the RIL signal remains and slowly returns to zero.

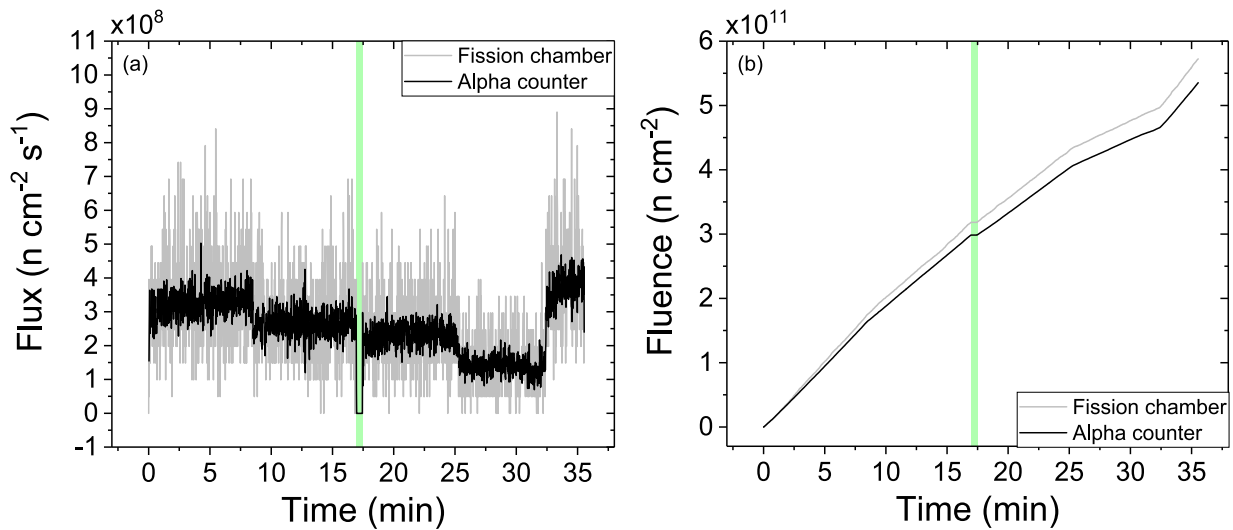


Fig. 2. Neutron flux (a) and fluence (b) kinetics on the fiber, monitored through the alpha counter (black) and fission chamber (grey) provided by the FNG facility. The green area highlights a 28-seconds period during which the neutron beam was stopped. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

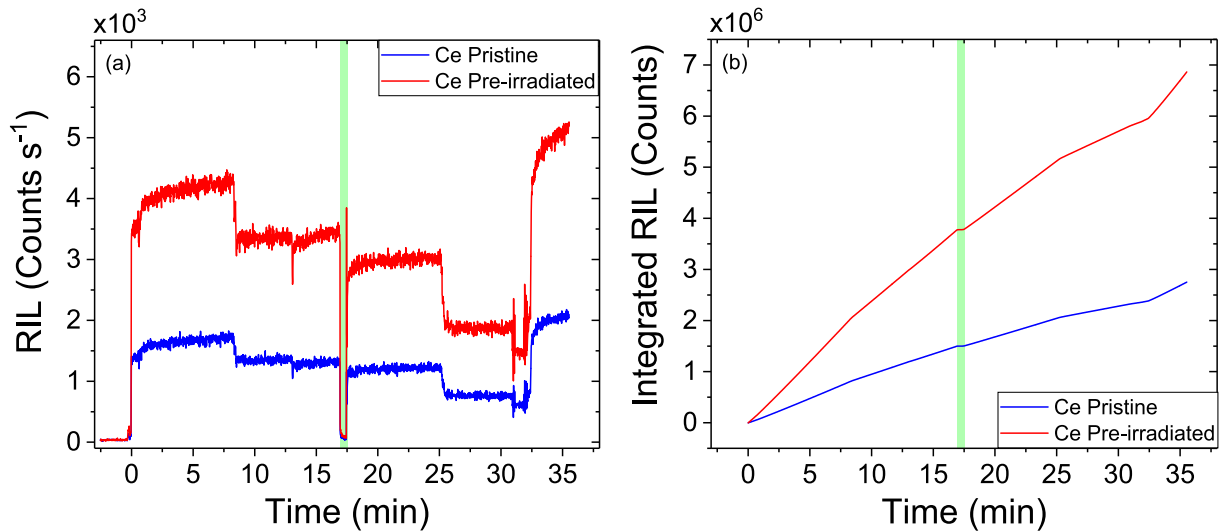


Fig. 3. RIL (a) and integrated RIL (b) kinetics for the pristine (blue) and pre-irradiated (red) fibers. The green area highlights the same 28-seconds irradiation stop period of Fig. 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.3. Calibration of the two optical fibers

As the RIL kinetics acquired with the PMTs and the neutron kinetics obtained with the alpha counter have the same integration time of one second, it is possible to plot one quantity as a function of the other and directly check the linearity of the response. Were this be confirmed, the sensitivity which will permit the calibration of the two fibers as neutron flux sensors can be computed. For this evaluation, Fig. 4a shows a scatter of points representing the measured RIL as a function of the neutron flux. The plot has a monotonic tendency, which can be exploited to calculate the linear fits (solid lines). The large deviations of the points in Fig. 4a can be explained by the combined fluctuations of the alpha detector and of the fibers, together with the imperfect synchronization between the two detectors. Especially on the scatter plot of the pre-irradiated sample, there appears a division in 5 discrete groups of RIL values. These correspond to each of the 5 steps that can be observed in Fig. 2a and Fig. 3a, during which the neutron flux was at an almost constant level. In Fig. 4b, the linearity is even clearer, as the cumulative nature of fluence reduces the influence of desynchronization errors between the detectors.

In this case, the kinetics of the measured RIL follow almost perfectly the kinetics of the neutron fluence measured through the alpha counter, up to the point that the dashed lines of the data are almost indistinguishable from the fit curves. All the linear fits shown in Fig. 4 are simple linear regressions with the value at origin fixed at zero to give physical meaning to the fits. The results of the linear fits are reported in Table 1, in the form of the adjusted R^2 value, to roughly quantify the linearity, and the sensitivity, for the calibration of the fibers once the linearity is confirmed.

The adjusted R^2 values for both the fit on the flux measurement (>0.982) and on the fluence measurement (>0.99996) indicate a very good agreement between the RIL and alpha counter datasets. In particular, the fluence datasets between the detectors are very compatible because, as mentioned before, of the lower influence of desynchronization errors in the detectors on a cumulative measurement. These results enable then the possibility to calibrate the two optical fibers as neutron monitors. The sensitivity values obtained with the two methods are close, but they differ in the associated error, which is two orders of magnitude lower for the curve as a function of the fluence of

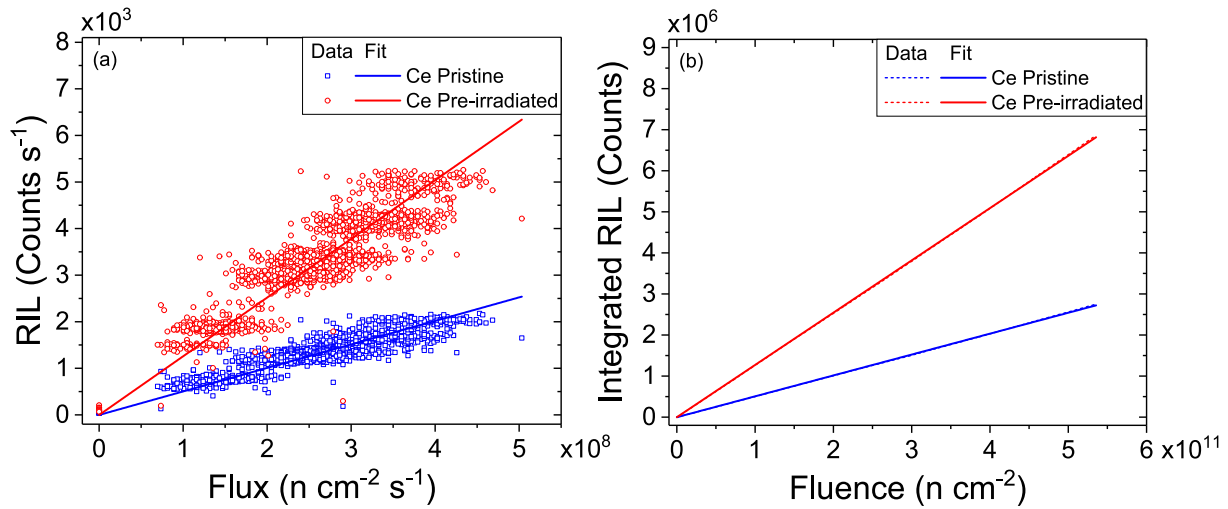


Fig. 4. RIL as a function of the flux (a) and integrated RIL as a function of the fluence (b), both measured by the alpha counter. The solid lines report the linear fits used to find the sensitivity needed to calibrate the two fibers.

Table 1

Calculated adjusted R² values and sensitivities of the two linear fits.

	Flux		Fluence	
	Adj. R ²	Sensitivity	Adj. R ²	Sensitivity
Units		Counts n ⁻¹ cm ²		Counts n ⁻¹ cm ²
Ce Pristine	0.982	$5.05 \times 10^{-6} \pm 1.5 \times 10^{-8}$	0.99996	$5.0873 \times 10^{-6} \pm 7 \times 10^{-10}$
Ce Pre-irradiated	0.983	$1.26 \times 10^{-5} \pm 4 \times 10^{-8}$	0.99998	$1.273 \times 10^{-5} \pm 1.13 \times 10^{-9}$

Fig. 4b. This is also highlighted by the higher R² value. This result proves the sensitivity values calculated on the fluence to be the most reliable for a calibration. As for the comparison between the pristine and pre-irradiated samples, the higher sensitivity of the pre-irradiated sample is confirmed again, with a sensitivity value 2.5 times higher than the pristine one. The R² value is slightly higher on the pre-irradiated sample, which would be coherent with the improved dosimetric properties which usually come with the pre-irradiation, but the difference is too

small to draw any conclusion.

3.4. Validation of the calibration

To evaluate the quality of the calibration performed in the previous section, the sensitivity coefficients of the two fibers are used to estimate the neutron flux and fluence during another measurement. Around 10 s after the first run was finished, the irradiation restarted without any change in the setup. As they were proven the most precise, the sensitivity values calculated from the fits in Fig. 4b were used to estimate the neutron flux and fluences from the RIL kinetics during this second run. The measured kinetics are then compared with the results given by the alpha counter and the fission chamber of the facility in Fig. 5. To improve the readability of the graphs, the two kinetics from the facility have been smoothed via a moving average algorithm with a 3 s window. The curves shown in Fig. 5 then confirm the capability of both fibers to faithfully follow all kinetics with less fluctuations than the facility counters, results that are especially highlighted in the flux plot in Fig. 5a.

Here, both fibers easily follow the changes in the neutron flux. Even more, they clearly show all variations that might be indistinguishable

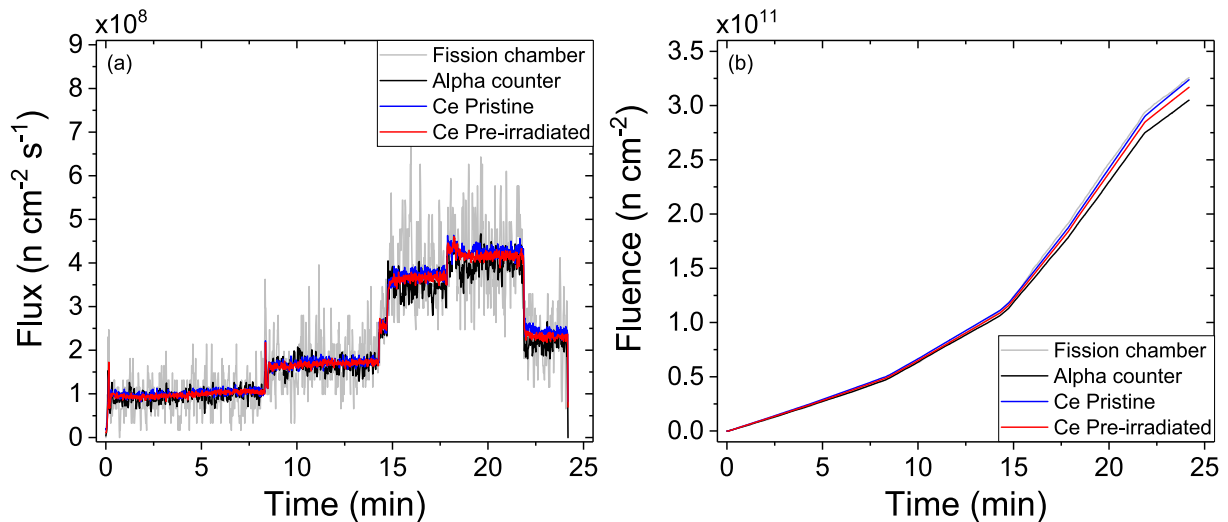


Fig. 5. Flux (a) and fluence (b) kinetics, obtained with the instruments of the facility (fission chamber, alpha counter) and with the two optical fibers. To make the graph more readable, the grey and black curves have been smoothed with a moving average algorithm, with a 3 s window. The results with the optical fibers were calculated using the sensitivities obtained with the fits in Fig. 4b on the integrated RIL kinetics.

from the noise of the facility counters. When comparing the fluence kinetics, in Fig. 5b the difference between the fibers and the reference sensors is less marked, but they all follow the same trend, with very close values, with a cumulative error that stays between the two instruments of the facility, up to a final deviation from the alpha counter of 6 % for the pristine fiber and 4 % for the pre-irradiated one, at the maximum fluence of $3.2 \times 10^{11} \text{ n cm}^{-2}$. To complement the visual comparison in the validation process, the root mean squared error (RMSE) is calculated between the results obtained with the alpha counter, with the two optical fibers and with the fission chamber, for comparison. The calculations were done using the smoothed datasets of the facility counters, as it was done for Fig. 5. This did not impact the results for the fluence, but notably reduced the RMSE between the two counters of the facility. The results of this analysis are reported in Table 2.

The RMSE analysis describes the average magnitude of the prediction errors between two datasets. It computes the standard deviation between a reference measurement (in this case the alpha counter) and a measurement in need of validation (fibers, fission chamber). The relative RMSE was calculated as the RMSE divided by the average value of flux (fluence) for each instrument. The RMSE_{REL} results show, for both flux and fluence measurements, the quality of the calibration of the optical fibers compared with the fission chamber. The two fibers show a $\sim 12\%$ and $\sim 10\%$ error, for the pristine and pre-irradiated samples, respectively, much lower compared to the $\sim 30\%$ of the fission chamber. These values go down to $\sim 7\%$, $\sim 4\%$ and $\sim 8\%$ when looking at the fluence measurement, again for the lower desynchronization error on a cumulative measurement. The relative errors are also again lower for the pre-irradiated sample, this time in a significative-enough way so that it is possible to confirm the improved dosimetry properties (other than the higher sensitivity) of a pre-irradiated Ce-doped fiber. Being this small, these errors can be explained by the uncertainty in the positioning of the fibers compared to the tritiated target, hence the ratio to obtain the neutron flux/fluence at a certain position from the total neutron yield of the reaction. These errors also contain information about the parasitic effects of RIL-based measurements described in the introduction, among which the stem effect that was neglected, as mentioned in Section 2.3. These results prove the quality of the calibrations obtained from the first run, and attest the capability of these optical fibers to act as neutron flux and/or fluence monitors.

4. Conclusions

The results presented in this work show the qualification, calibration and validation of two Ce-doped radioluminescent optical fibers to act as flux and fluence monitors for 14 MeV neutrons. Their capabilities have been proven across two irradiation runs at the Frascati Neutron Generator, the first one to evaluate the linearity of their responses and their sensitivity to 14 MeV neutrons. The second one to validate the calibration. It is worth mentioning that the calculated sensitivity values are for the whole setup, from the 2 cm sensitive fibers, through the 25 m transport fibers and to the PMTs used here. To be used as a flux/fluence monitor with this sensitivity, the whole setup would need to be perfectly replicated at the new irradiation site. To generalize the calibration and widen the use cases of the setup, proper repeatability and reproducibility studies are required, and will be the object of a future work. The results of the validation run show a very low relative error for the two optical fibers, when compared to the alpha counter and the fission chamber of the facility. These errors will need to be better addressed and improved in future works, but the simplicity of the setup paths the way to many possible improvements: quicker acquisition systems, shorter transport fibers and purposely-engineered sensitive fibers. These could implement mirrors on the exposed end of the sensitive fiber to improve the signal-to-noise ratio, or darker coatings to better protect from the ambient light, among other solutions (Vidalot, 2023). The fluences and fluxes explored in this work are on the lower end of what will be encountered in most zones of fusion reactors, and, even if they will need

Table 2

Absolute and relative root mean squared errors (RMSE) comparison between the alpha counter (α) and the other detectors.

Units	Flux		Fluence	
	RMSE	RMSE_{REL}	RMSE	RMSE_{REL}
	$\text{ncm}^{-2}\text{s}^{-1}$		ncm^{-2}	
Ce Pristine – α	2.62×10^7	0.11751	7.98×10^9	0.067027
Ce Pre-irradiated – α	2.23×10^7	0.10224	5.01×10^9	0.042976
Fission chamber – α	6.76×10^7	0.30146	9.76×10^9	0.081833

to be confirmed with more thorough experiments, results like the 12-decades linearity of RIL-based dosimeters under X-ray irradiation already suggest that they should continue to work at higher fluxes and fluences. (Vidalot, 2022) Were that confirmed, future fusion reactors could then gain from the numerous advantages of optical fibers and from the here-proven good performances as 14 MeV neutron detectors to improve the quality of the neutron mapping around the facility, with a small and simple solution like the one presented here. Even more, the direct monitoring of the neutron output of magnetically confined plasma or ignition shots would enable the direct characterization of the fusion output, even though this would need properly prepared optical fibers, capable of withstanding very harsh conditions on top of radiations.

CRedit authorship contribution statement

Luca Weninger: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Adriana Morana:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Andrea Colangeli:** Writing – review & editing, Project administration. **Fiammetta Fricano:** Writing – review & editing, Methodology. **Youcef Ouerdane:** Writing – review & editing, Resources, Funding acquisition. **Emmanuel Marin:** Supervision, Funding acquisition. **Aziz Boukenter:** Supervision, Project administration, Funding acquisition. **Stefano Loreti:** Writing – review & editing. **Antonino Pietropaolo:** Writing – review & editing. **Sylvain Girard:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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