

Physics for Health:

New perspectives in medical applications and radiation safety



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“Overcoming Diffusion and Auto-Oxidation Artifacts in Fricke Dosimetry via Physics-Informed Neural Networks”

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Fricke gel (FG) dosimeters have attracted considerable interest in radiotherapy thanks to their capability to map three-dimensional dose distributions (DDs). These systems exploit the radio-induced oxidation of ferrous (Fe^{2+}) to ferric (Fe^{3+}) ions, using the concentration of Fe^{3+} —detectable via magnetic resonance due to its paramagnetic properties—as a quantitative marker of absorbed dose. Alternatively, by adding a chelating agent such as xylenol orange (XO) or methylthymol blue (MTB), DDs can be retrieved through optical transmittance measurements.

Despite their good sensitivity, linearity, and spatial resolution, the clinical use of FG dosimeters remains limited by their short usable lifetime. Although the gel matrix restricts ion mobility, diffusion still occurs, producing blurring in the measured DD. Moreover, chelating agents induce auto-oxidation (AO) processes that alter the relationship between absorbed dose and Fe^{3+} concentration. Both diffusion and AO depend on the time elapsed between preparation/irradiation and measurement, creating a mismatch between FG dosimetry and the logistical constraints of radiotherapy workflows.

Most research in this field has focused on optimizing chemical formulations to mitigate ion diffusion and AO. In this work, we present an AI-based post-processing technique that enables accurate DD reconstruction when diffusion and AO have already occurred. The method relies on Physics-Informed Neural Networks (PINNs): by modelling the underlying physical processes, the network effectively performs a synthetic inversion in time, recovering the original DD from degraded measurements.

We demonstrate that this approach is robust and general with respect to gel composition and problem dimensionality. It yields DDs with low mean-squared errors ($\sim 10^{-6}$ – 10^{-5} OD²) and high gamma-analysis passing rates (>95%). Finally, we show that the effective utilization time of FG dosimeters can be extended by at least an order of magnitude.