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Transit dose measurements using alanine and diode-based dosimeters

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ABSTRACT

The growing interest in low-dose (< 100 Gy) radiation processing applications has raised concerns about accurately measuring the absorbed dose in irradiated materials. Depending on the irradiator design, the transit time due to the radioactive source movement (or the product itself) until the stable irradiation position might affect the predicted absorbed dose. This work aims to evaluate the transit dose in a ^{60}Co Gammacell 220-Nordion irradiator, which has radioactive sources settled at the bottom of a lead shielding. When the facility is on, the product and the dosimeter are mechanically guided down to the irradiation position, and hereafter the selected exposure time starts to be counted. At the end of irradiation, both product and dosimeter rise to the initial position enabling them to be gathered by the operator. The product is continuously irradiated at different dose rates during its fall and rise movement, preventing the transit dose from being obtained straightforward. The experimental approach adopted is to assess the transit time, and thus the transit dose, using an online diode-based dosimetry system previously calibrated against reference standard alanine dosimeters. The agreement between the transit doses attained with the diode (0.41 ± 0.02) Gy and alanine (0.38 ± 0.01) Gy validates the method herein proposed.

Keywords: **Si diode, transit dose, gamma radiation processing, high-dose dosimetry.**

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1. INTRODUCTION

The growing interest in low-dose (≤ 100 Gy) radiation processing applications has raised concerns about accurately measuring the absorbed dose in irradiated materials. Depending on the irradiator design, the transit dose due to the radioactive source movement (or the product itself) until the stable irradiation position might affect the predicted absorbed dose. The contribution of the transit dose is usually neglected in most routine processes covering doses of tens kGy [1, 2], but it is likely to be significant to low-dose processes. This dosimetric issue also arises in intensity-modulated radiation therapy (IMRT) [3, 4] and high dose rate (HDR) brachytherapy [5, 6], generally associated with the displacement of the source between the dwell irradiation positions. Several techniques have been proposed to evaluate the transit dose component, but most are based on ionization chambers and electronic portal imaging devices (EPID), unsuitable for radiation processing dosimetry [7-10].

This work aims to evaluate the transit dose of a small-scale gamma irradiator using a house-made dosimetry system based on a PIN photodiode operating in short-circuit mode without an externally applied voltage. In this operating condition, the primary dosimetric parameter is the radiation-induced current, whose intensity is proportional to the dose rate. The advantage of real-time acquisition of the current signal is that the transit time can be assessed by analyzing the signal profile, which is impossible to achieve with passive dosimeters.

The irradiator employed is a ^{60}Co Gammacell 220-Nordion with a radioactive source loaded at the bottom of a lead shielding. When the facility is on, the product and the dosimeter are mechanically guided down to the irradiation position, and hereafter the selected exposure time starts to be counted. At the end of irradiation, both product and dosimeter return to the initial position enabling them to be gathered by the operator. During each fall and rise movement, the product is continuously subjected to different dose rates, and, therefore, the transit absorbed dose is not straightforwardly obtained. The experimental approach adopted relies on assessing the transit time through the output current signals delivered by the diode at sequential irradiation cycles. The charge obtained offline via integrating each current signal recorded during the transit time is linked to the transit dose through the diode dose-response calibration. The results obtained are benchmarked against those assessed with alanine dosimeters.

2. MATERIALS AND METHODS

A house-made dosimetry system used in this work is based on an unbiased photodiode (SFH 206K, Osram), capable of operating in either current (online) or charge (offline) mode. A detailed description of this dosimetry system and its performance characteristics can be found elsewhere [11]. Under irradiation, the output current readings are performed by a Keithley 6517B electrometer. For analysis, the data is sent to a personal computer via a General Purpose Interface Bus (GPIB) controlled by software developed in LabView.

Irradiations are carried out at room temperature (21º C) using a ^{60}Co Gammacell 220-Nordion at a dose rate of 447.90 Gy/h. The dose-response curve given by the charge (achieved by integrating the current signal from the diode) as a function of the dose is assessed between 3.7 and 18.7 Gy. The linearity of the dose-response and the corresponding charge sensitivity, obtained from the slope of the curve, are also investigated.

The transit time is assessed by analyzing the variation of the current intensity delivered by the diode as a function of the exposure time. Twenty current signals are consecutively acquired by switching the facility on and off to improve the accuracy of the transit time. The corresponding transit dose to each irradiation cycle is attained offline using the dose-response curve of the diode.

For comparison purposes, three 36.5 mg alanine dosimeters from Aerial® are irradiated with the diode over twenty irradiation steps to achieve the accumulated dose within the operational dose range of alanine (10 Gy-150 kGy). The spectrum acquisition is performed with an MS400 EPR spectrometer (Magnettech, Berlin) equipped with the AerEDE dosimetry software (Aerial®, France), under the following parameters: microwave power of 8 mW, magnetic field centered at 3370 G with field sweep of 30 G, ten scans, sweep time of 12 s, a gain of 10^2, and 180 ° phase. Using the dose calibration curve, earlier obtained under the mentioned conditions within the range of 5 Gy-100 Gy, and the average of the three accumulated dose readings, the transit dose is determined. The uncertainty components of the current and charge data, in addition to those of statistical origin, are derived from the diode reading, the electrometer accuracy, and the time acquisition. All expanded uncertainties results are calculated with a coverage factor (k=2) to provide a 95% confidence level.

3. RESULTS AND DISCUSSION

The output current signals consecutively recorded at twenty cycles of the diode movement are shown in Figure 1. They all exhibit the same gaussian pattern: the current increases as the diode descends towards the source, reaches its maximum value (84.4 ± 0.1) nA at the steady-state irradiation, and decreases when it ascends back to its initial position. The average transit time (7.20 ± 0.02) s is attained by analyzing the fall and rise times of the whole set of current signals. The integration of all current signals delivered by the diode leads to the average charge generated in its sensitive volume as (278.2 ± 1.9) nC. In Figure 2, these parameters are shown in an expanded view of a current signal to help the reader.

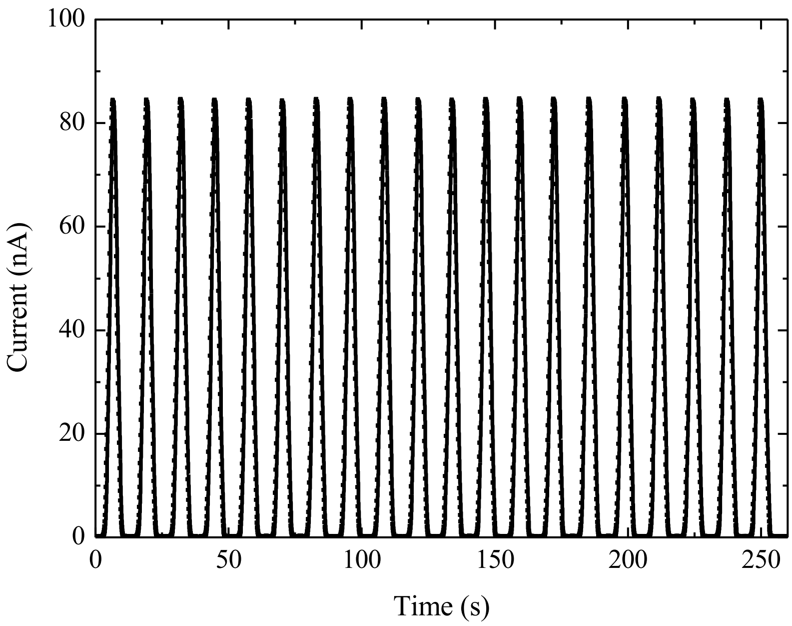

Figure 1: *Twenty output current signals continuously recorded during the diode movement by switching the source on and off.*

To accurately assess the transit dose, based on the correlation between the average charge and the energy (or dose) deposited on the diode during its transit time, the dose-response of the dosimetry system covering doses less than 20 Gy is investigated. Five current signals, acquired in steps of irradiations to 447.90 Gy/h at exposure time spanning 30 to 150 s, are depicted in Figure 3. They are very stable with a coefficient of variation CV (percentual ratio of the standard deviation to the average value) better than 0.2%.

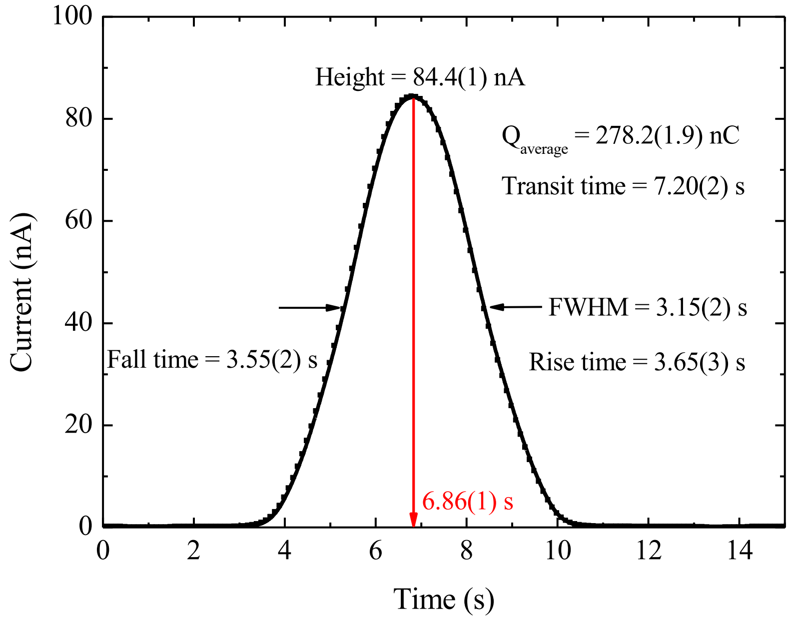

Figure 2: *The expanded view of one current signal delivered by the diode during its fall and rise movement.*

The charge produced on the diode at each irradiation step, gathered with the current signal data disclosed in Figure 3, is plotted against the dose in Figure 4. It evidences the dose-response linearity with a (679.9 ± 1.5) nC/Gy charge sensitivity and a correlation coefficient better than 0.99998. Thus, the charge sensitivity and the average charge delivered by the diode during transit enable the transit dose (0.41 ± 0.02) Gy to be determined. This result is benchmarked with that assessed with alanine dosimeters using a calibration curve presented in Fig 5, where the EPR amplitude, given by the peak-to-peak amplitude of the central signal of the EPR spectrum, is normalized to the dosimeter mass. From the calibration curve, the average value of the accumulated dose in twenty irradiation cycles is (7.52 ± 0.2) Gy, which leads to a transit dose of (0.38 ± 0.01) Gy. This result fairly agrees with that assessed with the diode and thus validates the method proposed in this work.

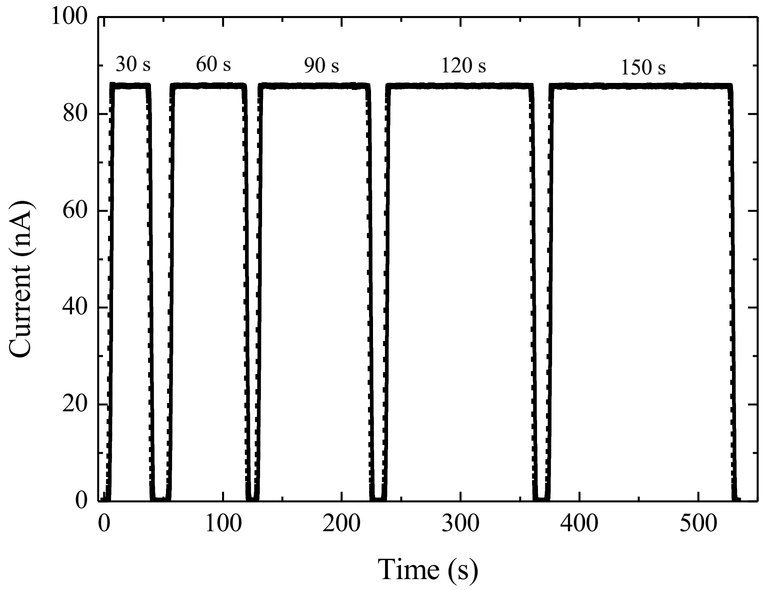

Figure 3: *Current signals delivered by the diode irradiated at 447.90 Gy/h under different exposure times.*

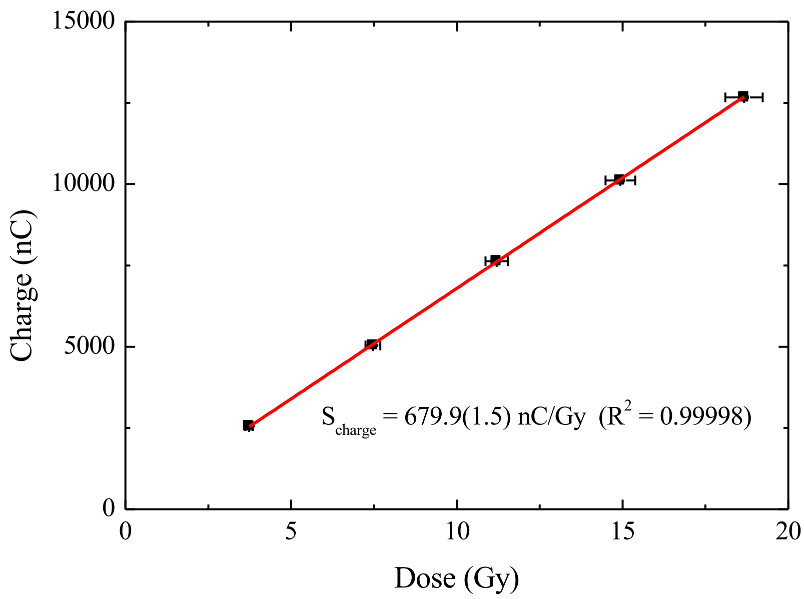

Figure 4: *Dose-response curve of the dosimetry system within the dose range of 3.7-18.7 Gy.*

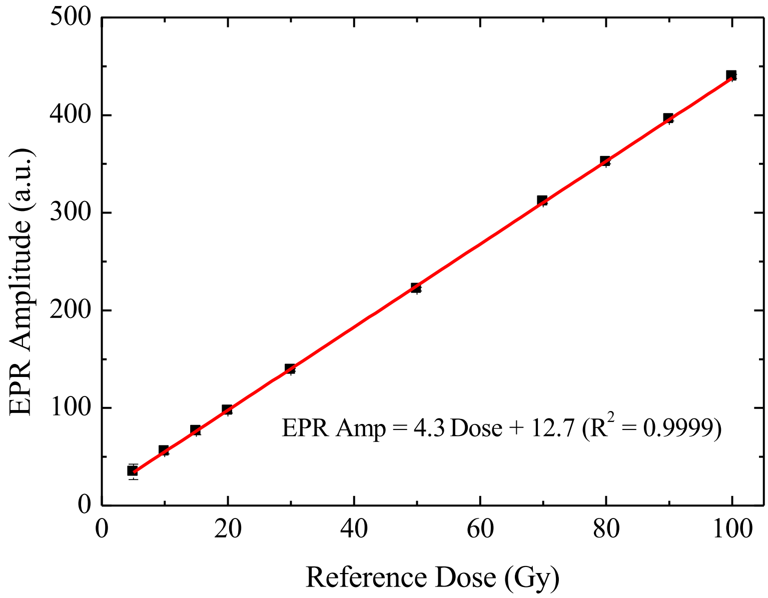

Figure 5: *Calibration curve of the alanine dosimeters within the 5-100 Gy dose range.*

4. CONCLUSIONS

A simple and fast method for measuring the transit time and, hence, the transit dose of a small-scale ^{60}Co gamma irradiator is proposed. It is based on monitoring the output current from a photodiode, operating in the short-circuit mode, during its movement toward the radioactive source. The current signal profile analyses provide data on dose rates at each irradiation position, the transit time, and the correspondent transit dose. The online assessment of these parameters, which is impossible for any passive dosimeter, is a key advantage in radiation processing dosimetry. Furthermore, the accuracy of the results, experimentally validated with alanine dosimeters, corroborates the suitability of the proposed method for transit dose measurements.

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