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# EFFECTS OF THE INTERRUPTION OF THE IRRADIATION PROCESS ON PMMA HARWELL INDUSTRY DOSIMETRY SYSTEMS

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## ABSTRACT

Nowadays, the use of dyed-polymethylmethacrylate dosimetry systems in measurements at industrial irradiations has been broadly, despite the use of alanine dosimeters. Accurate dosimetry measurements are essential for the sterilization applications of medical products as well as the preservation of food by ionizing radiation. Regulations in many countries require in-plant dosimetry to ensure that the specified radiation dose has been delivered to the product. Harwell commercial dosimeters commonly are built to work with measurements between 1 kGy to 50 kGy, this means that a same dosimeter could be used until reach these values. Radiation processing demands partial measurements of the absorbed dose to guarantee the final desired applied absorbed dose depending to the dose rate. In this sense, the total absorbed dose corresponds to the cumulative partial values. In this study, several dosimeters were irradiated at the Multipurpose Gamma Irradiation Facility at IPEN – CNEN/SP to evaluate the response to the interruption of the irradiation process in the total cumulative absorbed dose values considering statistical changes and some processing parameters. When studied the Harwell dyed-polymethylmethacrylate dosimeters Red 4034 and Amber 3042, applying processing interruptions, results shown a coefficient of variation under 7% for industrial irradiation conditions to the total cumulative absorbed dose.

## 1. INTRODUCTION

The employing of ionizing radiation have had several purposes, among which can listed applications such as crosslinking and degradation of polymers, graft polymerization, improvement of semiconductor properties, sterilization of medical devices and packing materials, laboratory animals feed disinfection, gemstones color enhancement, sterilization of human tissues for transplantation, etc.[1]. Last years disinfestation and disinfection using gamma radiation of cultural heritage objetcs fabricated with paper, wood, leather, bones, textiles etc. have increassing considerably.

Currently, most facilities and irradiation laboratories to manage the absorbed doses in irradiated products have used dyed-polymethylmethacrylate (PMMA) dosimeters. It has been widely used as routine dosimeters in the Multipurpose Gamma Irradiation Facility at IPEN – CNEN/SP. PMMA dosimeters have been provided by Harwell Dosimeters Ltd. UK, and the most used are Red and Amber Perspex types.

Particularly, when research materials are processed by gamma radiation is necessary to interrupt the irradiation process few times to check the absorbed dose and the dose rate of product. After this, the same dosimeter returns to the irradiation chamber to complete the total calculated dose. Some works were developed to study the effect of the interruption of process

[2], however no intermediate measurements of the absorbed dose of the dosimeters were performed. In this case, the goal of this work is to study the effect of the partial interruption of the radiation processing in the dosimetric measurements considering the influence of the room temperature and the radiation dose rate.

## 2. MATERIALS AND METHODS

### 2.1. Description of the Multipurpose Gamma Irradiation Facility

The Multipurpose Gamma Irradiation Facility at IPEN – CNEN/SP is a Category IV (IAEA classification) panoramic wet source storage irradiator and was designed for multipurpose applications. The sources consists of forty eight cobalt-60 source pencils placed and aligned on two racks (metal support structures) as showed in Fig. 1. The racks can be moved independently between two positions, at the bottom of a deionized water pool when the facility is no operating and at the top of the pool to reach the irradiation chamber level. The current installed activity is 10.4 PBq (280 kCi). Generally, the irradiations are performed in stationary mode, and the products are placed on aluminum tables in function of the desired dose rates.

**Figure 1: Racks with source pencils under the water pool.**

Because of the intrinsically characteristics of this facility related to the sources arrangement and distribution, different from laboratory irradiators (GammaCell systems), is necessary to qualify the irradiations results for more than one dose rate [3]. The Multipurpose Gamma Irradiation Facility is a semi-industrial irradiator, however also can be used for research objectives.

The irradiation chamber consists of a biological shielding of concrete and high-density metal and an internal volume (16 $m^3$) when the irradiation taking place. The access to the irradiation chamber is by a 115 ton sliding concrete block door moved by a hydraulic system.

### 2.2. Dosimeters

The studied dosimetry system was the PMMA manufactured by Harwell Dosimeters Ltd. Including the models are Red Perspex 4034 (batch LN, range 5 kGy – 50 kGy) and Amber Perspex 3042 (batch W, range 1 kGy – 30 kGy) both conditioned and individually sealed in labelled polyester/aluminum foil/polyethylene laminate sachets. The packaging material was specially selected to protect the PMMA from the effects of extremes of atmospheric humidity. The dosimeters are 30x11mm optically clear rectangular pieces of material produced in batches, for this reason in this study were used only the LN and W references fabrication numbers.

This dosimetry system requires accurately absorbance measurements by UV-VIS spectrophotometry because on irradiation the dosimeters visibility darken and the degree of darkening is related to the absorbed (water –equivalent) dose. The experimental data were obtained using UV-VIS spectrophotometer model Genesys 20, made by Thermo Spectronic. The recommended readout wavelength for the Red 4034 and the Amber dosimeters was 640nm and 651nm respectively. The thickness of the dosimeter was measured with a Mitutoyo digital micrometer. Then, the specific absorbance was calculated as the ratio between absorbance ant the thickness of dosimeter, normally expressed in units of $cm^{-1}$ or $mm^{-1}$. Finally, using a specific absorbance versus dose calibration polynomial equations each specific absorbance was converted to derived dose. The calibration polynomial equations were obtained by Dosimetry Lab from IPEN – CNEN/SP when the results have a coefficient of variation of ±2% [4].

The determination of ambient temperature from measurement room and from irradiation chamber, was performed by Minipa K-type thermometer, model MT-450.

## 3. RESULTS AND DISCUSSION

### 3.1. Initial considerations

As previously discussed, this kind of irradiation facility shows a rate dose variation depending of the irradiation position around the rack, then some particularly reference points were chosen by previous knowledge of dose rate distribution along the source racks (dose mapping) . Thus, three different points with three different dose rates have been chosen. In each point was placed a dosimeter to perform the measurement, as is showed in Fig. 2. The dosimeters were irradiated sequentially and individually to avoid errors in the measurements.

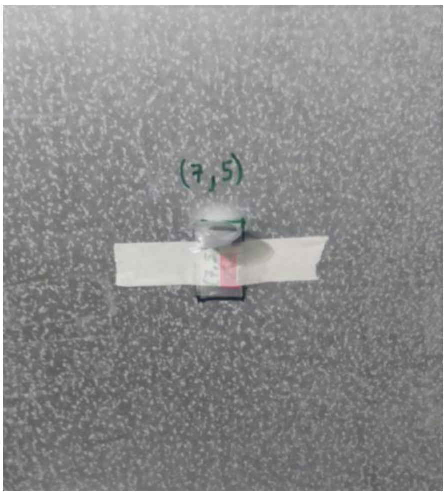


**Figure 2: Dosimeter fixed on rack protection.**

Three doses were chosen by each dosimeter, for comparative purposes. The results were divided as estimated dose and measured dose. The estimated dose was computed by the product of the dose rate by the irradiation the time in point with no interruptions. Already the measured doses were performed by interruption of twenty minutes between ($\Delta t$ = 20 min.) each irradiation stage for the same dosimeter. Table 1 shows the values of the measured dose rate achieved using the Red 4034 dosimeter as reference as well as the calculated estimated dose for each irradiation stage.

**Table 1: Estimated Dose References**

| Rack Position | Dose rate [kGy.h$^{-1}$] | Estimated doses (kGy) | | |
|---|---|---|---|---|
| | | $\Delta$t (stage 1) | $\Delta$t (stage 2) | $\Delta$t (stage 3) |
| 1 | 15.79 ± 0.16 | 9.21 ± 0.09 | 18.42 ± 0.19 | 27.63 ± 0.28 |
| 2 | 7.99 ± 0.08 | 7.99 ± 0.08 | 15.98 ± 0.16 | 23.97 ± 0.24 |
| 3 | 1.28 ± 0.01 | 1.93 ± 0.02 | 3.85 ± 0.04 | 5.78 ± 0.06 |

After each measurement, the dosimeter was replaced inside of original sachet and sealed with adhesive tape always manipulated using stainless steel tweezers.

The room temperatures used were 20 °C in the measurement room and 20.4 °C in the irradiation chamber. According with previous studies, only temperature above 40 °C can affect the measurements results [5],[6]. The dosimetry manufacturer recommendation is to work between 15 °C and 40 °C.

### 3.2. Results Analysis

The results were plotted in linear graphs, because the expected behavior of absorbed dose under a fixed dose rate.

The chi-squared test ($X^2$) was performed to verify existing divergences between the expected and the measured results [7] using 5% of significance and the results are showed in Table 2.

**Table 2: Statistical analysis**

| Dosimeter | Dose Rate [kGy.h$^{-1}$] | $X^2$ | Result test at 5% |
|---|---|---|---|
| Amber 3042 | 15.79 ± 0.16 | 2,381913 | passed |
| Amber 3042 | 7.99 ± 0.08 | 2,149707 | passed |
| Amber 3042 | 1.28 ± 0.01 | 2,872050 | passed |
| Red 4034 | 15.79 ± 0.16 | 2,170200 | passed |
| Red 4034 | 7.99 ± 0.08 | 2,062331 | passed |

The statistical analysis of the standard deviation has shown that the results can be accepted as near to the expected values as a preliminary approach, however, is necessary to verify the results acceptability individually.

As showed in Fig. 3 to 6, for 15.79 kGy.h$^{-1}$ and 8,99 kGy.h$^{-1}$ (selected high dose rates), when calculated the coefficient of variation of the measured absorbed dose, it not exceeded 7% in relation to estimated dose. These results are independent of type of dosimeter (Amber or Red). For industrial irradiations, depending of the processed material can be admitted a coefficient of variation until 10%.

Already for the low dose rate, as showed in Fig. 7, the coefficient of variation exceeded 20%. Despite statistical tests were approved, is necessary to calculate a correction factor to perform irradiations with considerable interruptions.

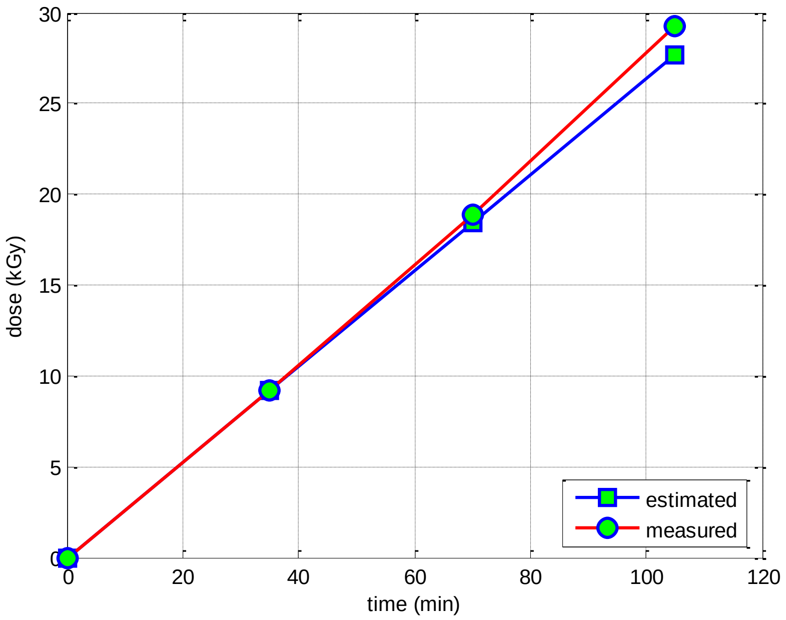


**Figure 3: Results for PMMA Amber dosimeter. Dose rate= 15.79 kGy.h$^{-1}$**

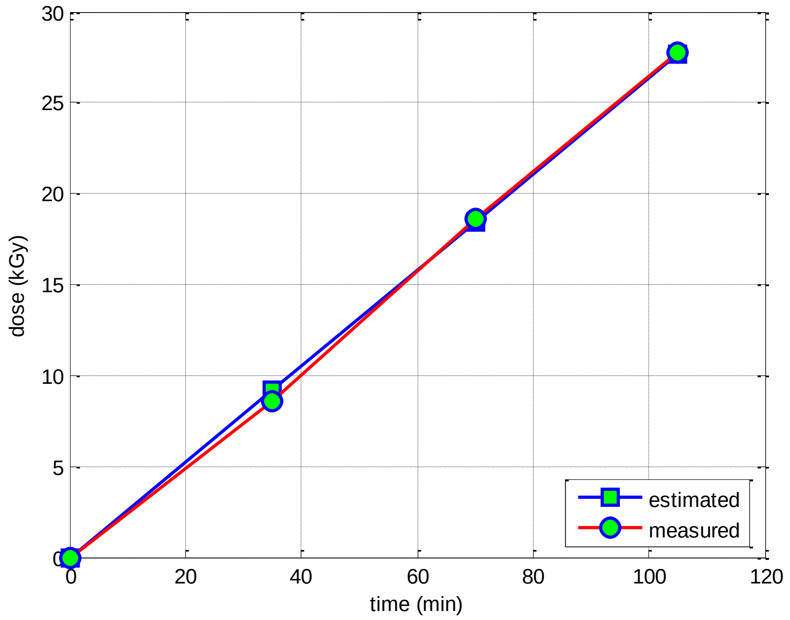


**Figure 4: Results for PMMA Red dosimeter. Dose rate = 15.79 kGy.h$^{-1}$**

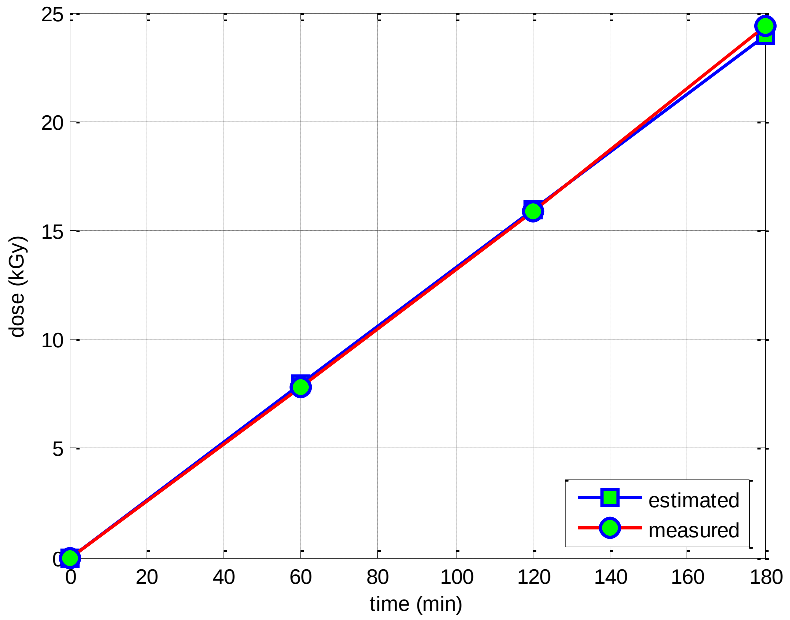


**Figure 5: Results for PMMA Amber dosimeter. Dose rate = 8.99kGy.h$^{-1}$**

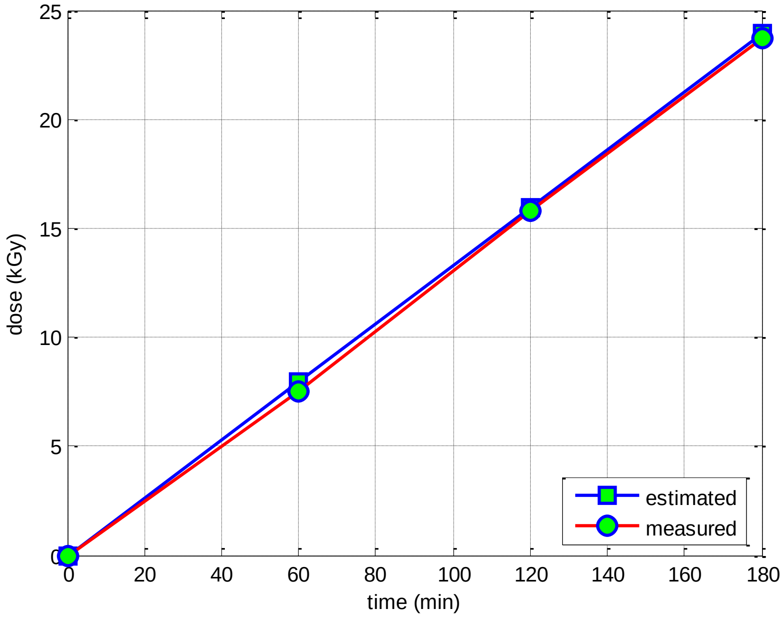


**Figure 6: Results for PMMA Red dosimeter. Dose rate = 8.99 kGy.h$^{-1}$**

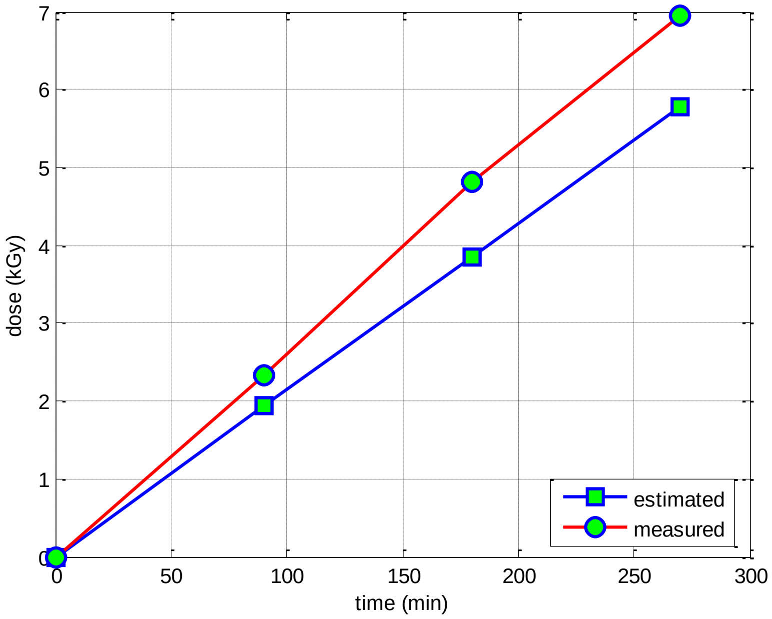


**Figure 7: Results for PMMA Amber dosimeter. Dose rate = 1.28 kGy.h$^{-1}$**

## 4. CONCLUSIONS

Generally, industrial radiation processing needs to be performed with interruptions of the process. Usually the average industrial dosed rate is between 5-6 $kGy.h^{-1}$ and unlikely to find dose rates lower than 2 $kGy.h^{-1}$.This work shows that is possible to interrupt the irradiation to measure dosimeter, replace the same ant continue the irradiation within the industrial irradiation conditions. This study reinforces the recommendation that routine dosimeters must be calibrated under conditions as close as possible to those in the irradiation facility itself (e.g. in-plant) [8].

Future studies will be developed to determine the dose rates range to do not affect the total cumulative absorbed dose when interruptions of the process are necessary.

## ACKNOWLEDGMENTS

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