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Study of pmma dosimeters response against storage temperature and post-irradiation time

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Abstract. In ensuring the correct amount of the absorbed dose received, the proper treatment in dosimeter measurement is needed due to several factors that can affect the measurement results. Therefore, the observation focuses on the measurement results of the absorbed dose of type 3042 AA Harwell fabrication-PMMA dosimeter against storage temperature and post-irradiation time. The dosimeter is irradiated using Gamma Cell Upgrade 220 with a dose rate of 4,718 Gy/hour and a target dose of 10 kGy and 25 kGy. Irradiated dosimeters are treated with storage temperatures at 4°C, 23°C, and 40°C and post-irradiation times at 0 hours, 1 hour, 1 day, 3 days and 7 days. The absorbed-dose measurements are compared with the calibration results of PMMA dosimeter with the Fricke standard. At the target dose of 10 kGy, it shows that the temperature of 23°C has the smallest average error that is 5.76% with a 7-day measurement tolerance time. A similar thing happened at the target dose of 25 kGy, it has the smallest average error of 1.81%. However, the target dose of 25 kGy shows that dosimeter cannot be stored at 40°C longer than 1 day due to error tolerance is reaching 46.09%.

1. Introduction

Irradiation service activities are the process of irradiating products using gamma rays to achieve specific goals. The quality of irradiation service activities depends on the accuracy of the absorbed dose received by the product by following the demand of irradiated service users in supporting the activities of irradiation services required quality management of the results of irradiation services. To ensure the quality of irradiation services is achieved good, methods that can support these goals are needed, one of which is through the measurement of routine absorbed doses of irradiated products. Measurement of routine absorbency dose aims to determine the amount of absorbency dose received by irradiated products. The results of this measurement are the responsibility of BATAN as a facility owner to irradiated service users.

The absorbed dose value is obtained from the absorbance measurement related to the object to be measured. The object measured is the polymethylmethacrylate (PMMA) dosimeter fabricated by Harwell Ltd Co. There are two types of dosimeters used in the dosimetry activity of absorbing dose measurement, namely the Perspex Amber 3042 dosimeters with a measurement dose range between 1 to 30 kGy and Perspex Red 4034 dosimeters with a measurement dose range between 5 kGy to 50 kGy. In its calibration document, Harwell suggested dosimeters were measured over for two days [1]. KM Glover (1993) in his writing said that the dosimeter would increase its absorbance value if stored at temperatures above 50°C and there is no significant change in absorbance value if the dosimeter is kept up to 7 days [2].

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However, in reality, the measurement of the absorbed dose does not refer to the standard (precisely the measuring time after irradiation and storage temperature). Sometimes the dosimeter is measured directly after irradiation and not infrequently it is also measured more than one day after irradiation. This raises the question of whether the difference in treatment in the measurement will have an impact on the measurement results. Therefore, the objective is to observe the variation of measurement post-irradiation time and also the storage temperature after irradiation to answer the questions previously explained. So, with this observation, it is expected that the absorbed dose measurement refers to the measurement standard and the absorbed dose measurement results are the true value and can guarantee the quality of irradiation services.

2. Materials and Methods

2.1. Materials

The primary material used in this study is PMMA dosimeter type Amber 3042 AA, fabrication from Harwell. This dosimeter has a measurement dose range from 1-30 kGy with a measurement wavelength at 603 nm or 651 nm. This dosimeter has dimensions of 30 mm x 11 mm with a thickness of 3 ± 0.55 mm [1].

2.2. Irradiation Process

Dosimeters still packaged in sealed sachets were irradiated at the Gamma Cell Upgrade 220 irradiator facility at PAIR BATAN, Pasar Jumat. Gamma Cell has a dimension of irradiation chamber that is 15 cm high and 20 cm in diameter. During the irradiation process, the dosimeter is placed right in the middle of the irradiation chamber. The dosimeter was irradiated at a target dose of 10 kGy and 25 kGy at a dose rate of 4,718 Gy / hour and Co-60 activity of 6,489 Ci.

2.3. Treatment after Irradiation

Dosimeters that have been irradiated are given several treatments, including direct dosimeters measured using a UV-Vis Spectrophotometer. Also, besides other treatments, use variations in temperature and storage time after irradiation. Temperature variations used are 4°C refrigerator temperature monitored with temperature indicator, room temperature 23°C monitored using HTC-1 temperature and humidity indicator, and 40°C temperature which is conditioned in OSK 9561B oven made by Ogawa Seiki Co. Ltd. At the measurement time variations, the period time of one hour, one day, three days until seven days was chosen.

2.4. Measurement of PMMA Dosimeter Absorbed Dose

PMMA dosimeters that had been irradiated and treated with variations in storage temperature and time after irradiation were measured for absorbance using a UV-Vis U-2000 Spectrophotometer made by Hitachi at a wavelength of 603 nm for PMMA dosimeters with a target dose of 10 kGy. As for the target dose of 25 kGy, measured at a wavelength of 651 nm. After measuring the wavelength, the thickness of the PMMA dosimeter was measured using a Mitutoyo IP 65 screw micrometer. From the absorbance and dosimeter thickness measurements, specific absorbance values were obtained. By using the PMMA dosimeter calibration table against Fricke, the absorbed dose value was obtained.

3. Result and Discussion

3.1. Observation of the absorbance spectrum

The PMMA dosimeter (polymethylmethacrylate) is a dosimeter that is used as a routine control in measuring the absorbed dose of materials that are sensitive to ionizing radiation such as gamma rays. PMMA Amber 3042 AA dosimeters are transparent red when the conditions have not been irradiated. After the conditions are irradiated, the color becomes darker. So, to distinguish the dosimeter color before and after irradiated or to distinguish the dosimeter irradiated at a target dose of 10 kGy from the

dosimeter irradiated at a target dose of 25 kGy, it is carried out by measuring the absorbance spectrum at a specific wavelength. Harwell suggested measuring the absorbance of the dosimeter PMMA Amber 3042 AA at a wavelength of 603 nm or 651 nm. Therefore, a wavelength scan is performed first to ensure the peak wavelength spectrum. Wavelength scans were performed from 580 to 710 nm and found there are two peaks in that range. This is consistent with Harwell's calibration which suggests measuring absorption values at two wavelengths.

In the variation of storage temperature, Figures 1 and 2 show that at the target dose of 25 kGy, the absorbance obtained is higher than the absorbance value at the target dose of 10 kGy. This is in accordance with the theory of Lambert-Beer where the absorbed dose received by a product will be directly proportional to the absorbance value [3]. Other references also say that the longer the irradiation time, the optical density or absorbance will be higher because irradiation time is proportional to the absorbance will be higher because irradiation time is proportional to the absorbance spectrum is highest at 4°C, then 40 °C and the lowest absorbance peak at 23°C. This trend does not only occur within 1 hour, but for 3 days and 7 days also have the same trend. Different data are shown at 1 day where the peak of the absorbance spectrum is highest at 4°C, followed at 23°C and the lowest absorbance peak at 4°C.

Whereas under the same conditions at a target dose of 25 kGy with time after irradiation for 1 hour as shown in Figure 2, the peak of the absorbance spectrum is inversely proportional to the temperature at the peak of the absorption spectrum is highest at 4°C, followed at 23°C and the lowest absorbance peak at 40°C. Similar trends occur for all time variations after irradiation at a target dose of 25 kGy. So, the lower the temperature, the higher the peak of the absorbance spectrum.



Figure 1. Graph of the absorbance spectrum of dose target 10 kGy at 1 hour in temperature variations

Figure 2. Graph of the absorbance spectrum of dose target 25 kGy in temperature variations

In the post-irradiation time variations, Figure 3 shows the magnitude of the wavelength peak for 3 days and 7 days. Besides, the peak absorbance spectrum does not sequentially follow the time after irradiation because the highest absorption occurs at 1 day while the lowest absorption occurs at 3 days. Figure 4 shows the results that the longer the storage time, the absorbance will decrease except at 1 hour. The same thing has been observed by MF Watts (1999), which shows data that at 40°C, the specific absorbance has decreased from the storage time of 1 hour, 1 day, and 2 days [4].

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Figure 3. Graph of the absorbance spectrum of dose target 10 kGy at 40°C in post-irradiation time variations

Figure 4. Graph of the absorbance spectrum of dose target 25 kGy at 40°C in post-irradiation time variations

3.2. Observation of Absorbed Dose Values in Storage Temperature dan Post-Irradiation Time

From the observation of the absorbance spectrum that has been done, the peak wavelength is detected at around 598 nm - 605 nm and 648 nm - 654 nm. So that in the measurement of absorbance using a UV-vis spectrophotometer, the wavelength is set by following Harwell's provisions at 603 nm or 651 nm. Based on the Harwell calibration table, a wavelength of 603 nm can only detect a dose of 1 - 15.03 kGy while a wavelength of 6.51 nm can detect a dose of 1.02 - 30 kGy. The absorbed dose value is obtained by converting the specific absorbance value from the results of the PMMA Amber 3042 AA dosimeter calibration to Fricke as shown in Figures 4 and 5. Fricke is a standard dosimeter used in irradiator calibration activities. Therefore, the dosimeter PMMA Amber 3042 AA, which is a routine dosimeter, must first be calibrated against Fricke [5]. Luiz Carlos Duarte Ladeira (2015) also asserted that PMMA Amber dosimeters are indeed suitable for use as routine dosimeters as quality assurance in the irradiation process [7]. The calibration of PMMA Amber 3042 AA as in Figures 4 and 5 are obtained by using the polynomial approach so that figure 4 has the equation $y = 0.0022x^3 - 0.0357x^4 + 0.2289x^3 - 0.5349x^2 + 2.8662x - 0.356$ with $R^2 = 0.9999$ and figure 5 has the equation $y = 0.0237x^4 - 0.1298x^3 + 0.5794x^2 + 3.1302x - 0.0233$ with $R^2 = 1$.

Therefore, to measure the absorbed dose value at a target dose of 10 kGy, the dosimeter is measured at a wavelength of 603 nm. Meanwhile, to measure the absorbed dose value at a target dose of 25 kGy, the dosimeter is measured at a wavelength of 651 nm. Measurement data are described in table 1. In doses of 10 kGy, and 25 kGy, at a temperature of 23°C for 7 days shows the best data between the other two temperatures, this is strengthened by the calculation of the average tolerance in table 2 which at a storage temperature of 23°C has the smallest average tolerance is 5.76% and 1.81%. So, the optimum storage temperature is carried out at 23°C and can be measured up to 7 days [2]. Even in previous studies said that the dosimeter could be stored up to 10 days at ambient temperature (15-25°C) with changes in specific absorbance fall within $\pm 2\%$ [8].

Based on the dose rate calibration data using Fricke, the absorbed dose value based on calculations for the 10 kGy target dose is 9.986 kGy. Whereas the target dose of 25 kGy is around 24.96 kGy. The two values are then used as a reference value. Therefore, measurement tolerances are obtained by comparing the reference absorbance dose (based on calculations) to the absorbance dose measurement results.

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Figure 5. PMMA Amber 3042 calibration graph against Fricke at a wavelength of 603 nm



From table 2, it can be seen for a target dose of 10 kGy, the highest average tolerance value at a storage temperature of 4°C within one day after irradiation. Whereas at the target dose of 25 kGy, the highest average tolerance value is at a storage temperature of 40°C within seven days after irradiation. Table 1 also shows that from 1 day to 7 days after irradiation, the absorbed dose continues to decrease until 7 days, tolerance reaches 46.09% at 40°C. So, the dosimeter storage temperature after irradiation affects the measurement results because the dosimeter is susceptible to heat when irradiated and after irradiation too [6].

Dose	Store on Tomporature	Storage Time					
Target	Storage Temperature	Oh	1h	1d	3d	7d	
10 kGy	4°C	10.05	9.58	11.75	9.70	9.93	
	23°C		9.48	10.94	9.70	10.54	
	40°C		10.22	11.58	9.67	9.64	
25 kGy	4°C	23.66	25.58	25.77	25.19	24.61	
	23°C		25.38	25.77	24.99	24.42	
	40°C		24.52	21.68	17.63	13.45	

Table 1. Measurement Data on variations in temperature and time after irradiation

Table 2. Data of tolerance measurement of the dose absorbed against reference

Dose	Storago Tomporaturo	Storage Time					
Target	Storage Temperature	0h (%)	1h (%)	1d (%)	3d (%)	7d (%)	
10 kGy	4°C	0.59	4.07	17.66	2.87	0.57	
	23°C		5.07	9.55	2.87	5.54	
	40°C		2.34	15.96	3.17	3.47	
25 kGy	4°C		2.48	3.27	0.91	1.38	
	23°C	5,22	1.69	3.27	0.14	2.14	
	40°C		1.76	13.13	29.34	46.09	

A considerable tolerance value can be caused by several factors, including the unfavorable absorbance measurement steps such as dosimeter packaging conditions when irradiated. Usually, the dosimeter is irradiated in a tightly packed state to avoid damage [10]. Furthermore, the concentration

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factor of water becomes another factor [8], especially on dosimeters conditioned at 4°C because when measured, it turns out there is condensed the vapor and causes the dosimeter to become moist. So, before measuring the dosimeter, condensed vapor or water must be wiped with a tissue first [9]. So that the measurement is accurate because if the condensed vapor still sticks to the dosimeter, the absorbance value becomes unstable at the reading on the spectrophotometer.

4. Conclusion

The PMMA Amber dosimeter 3042 AA irradiated at a target dose of 10 kGy and 25 kGy showed the same results which the best temperature in the storage of the dosimeter before the measurement was at 23°C with a 7-day of measurement tolerance time was still considered good.

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