Indian Journal of Pure & Applied Physics
Vol. 54, April 2016, pp. 259-262

Measurements of dose rate for 10-16 keV Synchrotron X-ray photons at BL-16 beam line of Indus-2

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Received 26 March 2014; revised 10 July 2014; accepted 5 January 2015

Indus-2 is a 2.5 GeV electron synchrotron radiation source located at Raja Ramanna Centre for Advanced Technology (RRCAT), India. There is significant radiation exposure in the direct beam of synchrotron radiation due to its intense flux and low energy at synchrotron radiation beam line. In this paper, measurements of absorbed dose rate for mono chromatic synchrotron X-ray photon of energy ranging 10-16 keV is presented using various types of passive dosimeters, like $CaSO_4$(Dy) TLDs, LiF :Mg,Ti (TLD-100), and Gafchromic film EBT-2 at microfocus X-ray fluorescence spectroscopy beam line (BL-16). The measured results are also compared with theoretically calculated values. It is observed that LiF :Mg,Ti (TLD-100), and Gafchromic film EBT-2 show 3-6 times more absorbed dose rates as compared to calculated values whereas $CaSO_4$(Dy) TLD shows 10-20 times more absorbed dose rates.

Keywords: Synchrotron radiation, Absorbed dose rate, Dosimeter

1 Introduction

Indus-2 is an electron storage ring, which is operational at beam energy of 2.5 GeV for producing synchrotron radiation (hard X-rays) from its bending magnets. Presently, it is operating with beam current of 150 mA at beam energy 2.5 GeV. In a synchrotron, when charged particle passes through a dipole magnet, it experiences a centripetal acceleration, hence, it radiate synchrotron radiation. Synchrotron radiation is having continuous spectrum, tunable source with very high intensity and collimated beam. It is a clean and calculable source. The 26 synchrotron radiation (SR) beam lines are planned in Indus-2 for various research applications, out of which 13 beam lines are in operation and many are in installation stage[1]. In Indus-2, synchrotron radiation is produced in the X-ray region. It is brought to air for performing experiment. There is a probability of human exposure to high intensity synchrotron radiation. Measurement of absorbed dose rate due to synchrotron radiation at the beam lines is required for personnel protection. It is also very important in radiation dosimetry to estimate exact dose rate at low energy synchrotron X-ray, typically below 20 keV as thermo luminescence dosimeters over estimate the dose rate[2]. An effort has been made to estimate absorbed dose rate due to synchrotron radiation in beam line -16 using different kinds of available passive dosimeter like $CaSO_4$:Dy, LiF:Mg,Ti (TLD-100) and Gafchromic film EBT-2. It is reported that LiF: Mg, Ti TLD has energy independent response from 30 keV to 10 MeV, whereas $CaSO_4$: Dy has 200 keV to 10 MeV. Also, LiF: Mg, Ti TLD can respond from 0.01 mGy to 10 Gy, whereas $CaSO_4$: Dy can respond from 0.1 mGy to 10 Gy[2,3]. EBT-2 Gafchromic film shows energy independent response from 28 keV to 6 MeV covering the dose range 0.1 mGy - 8 Gy4[4,5]. Passive dosimeter like TLDs and Gafchromic films are well suited for dosimetry at particle accelerators as they are not affected by the magnetic fields and pulse nature of the beam. This paper describes the measurement setup and the experimental results. The expected surface dose rate on soft tissue is also calculated and compared to the obtained dosimeter readings.

2 Material and Methods

Microfocus X-ray fluorescence spectroscopy beam line (BL-16) at the Indian synchrotron radiation facility Indus-2 is installed on a bending-magnet source with a working X-ray energy range of 4-20 keV. The layout of the beam line is shown in Fig. 1.

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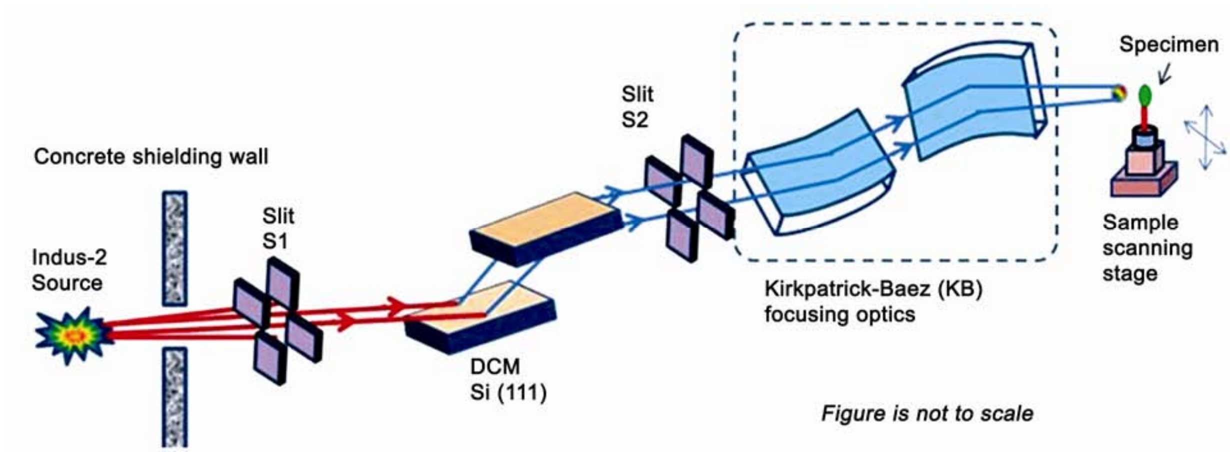

Fig. 1 – Layout of microprobe X-ray fluorescence Beamline (BL-16)

The beam line allows a user to perform X-ray fluorescence and total reflection X-ray fluorescence characterization of materials at micro and trace level. Apart from the elemental mapping, the beam line also provides other modes of XRF characterization, viz., grazing incidence X-ray fluorescence (GIXRF) analysis, chemical speciation, and near-edge absorption spectroscopy etc.[6] The beam line is having energy resolution of 10^{-3}-10^{-4} and with divergence of 0.05 mrad (horizontal), 0.29 mrad (vertical). Experiments at electron beam energy of 2 GeV were performed and during the experiments, beam current was changed from 30.5 mA to 28.3 mA. Passive dosimeters, like $CaSO_4$: Dy, LiF:Mg,Ti TLD and Gafchromic film EBT-2 were put after the S2 slit where the beam is monochromatic and collimated. During the experiment, collimated beam size was 7 mm × 20 mm with Gaussian beam shape. Samples were exposed free-in-air one by one for 100 s with photons of energy ranging from 10 keV to 16 keV at the beam line. Electron beam current were noted down for exposure of each set of samples. The experimental set up at bemline-16 is shown in the Fig. 2.

For estimation of collimated fluence rate of synchrotron X-ray photon after S_2 slit, photo diode AXUV-100 GX is put at the sample location. Photo diode current is noted down for incident photon energy ranging 10-16 keV. The fluence rate at respective photon energy was calculated using responsivity of the photodiode and it is given in the Table 1.

$CaSO_4$: Dy TLDs were in disc form with diameter 6 mm and thickness 1 mm. LiF:Mg, Ti TLDs were in form of rod having length 6 mm and thickness of 1 mm. Exposed $CaSO_4$: Dy and LiF:Mg, Ti TLDs have

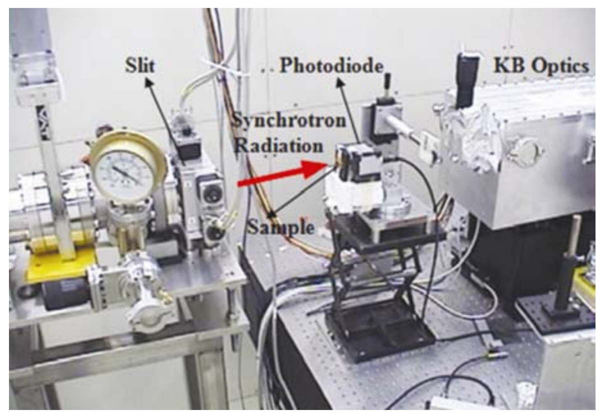

Fig. 2 – Experimental setup used for exposing passive dosimeters at Beamline-16 of Indus-2

Table 1 – Measured fluence rates of X-ray photon for photon energy ranging 10-16 keV at Beamline -16

Energy of photons (keV)	Photodiode current (A)	Photon fluence rate (Photon/mm^2/s)	Electron beam current (mA)
10	4.95E-09	1.93E+07	30.5
11	3.96E-09	1.73E+07	29.9
12	2.90E-09	1.37E+07	29.5
13	2.10E-09	1.12E+07	29.2
14	1.50E-09	8.34E+06	28.9
15	1.05E-09	7.28E+06	28.6
16	7.00E-10	5.46E+06	28.3

been read by reader Analyzer RA'94. The absorbed dose rates were obtained from the area under the glow curve using calibration factor. The calibration factor has been obtained as 233.5 counts/mGy for LiF:Mg,Ti and 1428 counts/mGy for CaSO4:Dy TLD with respect to Co^{60} exposure and we have selected the detectors groups which present TL response with sensitivity and reproducibility better than ±10%. Gaf-chromic EBT-2 films are cut into pieces of suitable size and then they were exposed to synchrotron radiation photon of energy from 10 keV to 16 keV in proper direction of the film surface. Relative sensitivity of Gaf-chromic EBT-2 films was within ±5% as specified by manufacturer. Photograph of the exposed EBT-2 films are shown in Fig. 3. Exposed portion of the film had become darker. Darkening increases with the energy deposition inside film. Exposed films have been scanned using high resolution flatbed scanner EPSON Expression 10000XL. For calibration purpose, EBT-2 films are exposed with known amount of dose from Co^{60} source and corresponding pixel values, optical density are estimated with the scanner and image-j software. From the pixel value of the exposed area of the films, one can get the absorbed doses using the calibration curve.

3 Results and Discussion

Dose rates measured by using $CaSO_4$: Dy, LiF:Mg,Ti TLD and Gafchromic film EBT-2 have been plotted in the Fig. 4. For comparison, the surface dose rate on soft tissue was calculated. The absorbed dose rate on the surface of the soft tissue can be calculated theoretically by using the analytical formula[7]:

$$D = \varphi E \frac{\mu_{en}}{\rho} \quad \ldots (1)$$

where φ is the photon fluence rate, E the energy of the photons and μ_{en}/ρ is the mass energy absorption coefficient[8] of absorbing medium. For example, for X-ray photon energy E=10 keV, φ =1.93×10^7 photon/mm^2/s, $(\mu_{en}/\rho)_{\text{soft tissue}}$= 0.440 m^2/kg. So, absorbed dose rate in soft tissue (ICRP) is $D_{\text{soft tissue,10 keV}}$ = 1.689 Gy/h/mA. Dose rates measured by using LiF:Mg,Ti TLD and Gaf -chromic EBT-2 film is showing 3-6 times more value with respect to calculated data, whereas $CaSO_4$: Dy TLDs are showing 10-20 times higher response, in the energy range studied. Estimated errors were within ±10%. The $CaSO_4$: Dy TLDs showed over response due to its high Z_{eff} as photoelectric effect is the dominant interaction mechanism in the energy range. Absorbed dose measured by $CaSO_4$: Dy TLDs had started decreasing below 11 keV due to self absorption inside TLD materials. Absorbed dose rate measured by Gafchromic EBT-2 film was the lowest among the dosimeters studied.

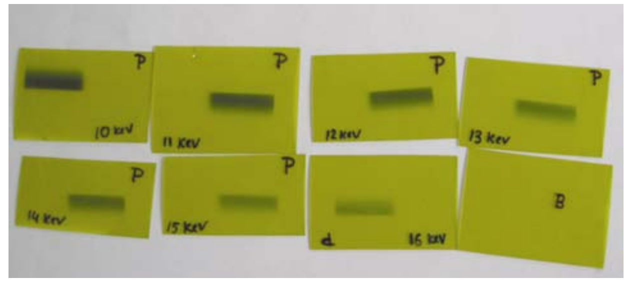

Fig. 3 – Gafchromic EBT-2 films after exposure in monochromatic synchrotron radiation of energy from 10 keV to 16 keV and film marked as ‘B’ is the unexposed one

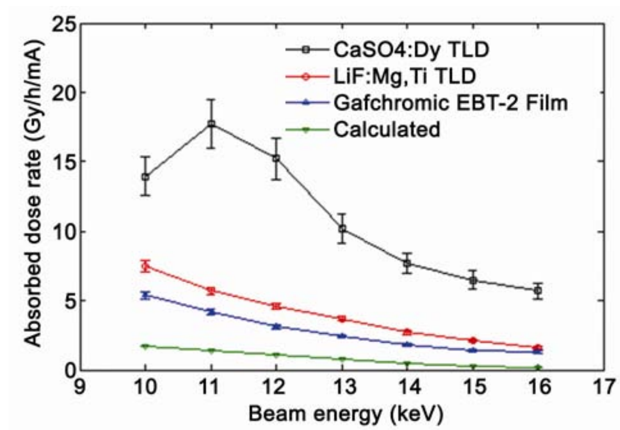

Fig. 4 – Plot of absorbed dose rate measured by using $CaSO_4$: Dy, LiF:Mg,Ti TLD, Gafchromic film EBT-2 dosimeter exposed to synchrotron beam of energy from 10 keV to 16 keV and as well as calculated value

4 Conclusions

Among different type of passive dosimeters used for estimation of absorbed dose rate at beamline BL-16, it is observed that absorbed dose measured by Gafchromic EBT-2 film is the most nearer to calculated value. So, Gafchromic EBT-2 film can be the best choice for performing low energy dosimetry at synchrotron radiation beam lines in 10-16 keV range. But, as Gafchromic EBT-2 films are not reusable and also have directional dependency, it is not recommended for use as a personnel dosimeter for radiation protection purpose. $CaSO_4$:Dy TLDs and LiF:Mg,Ti TLDs are reusable but $CaSO_4$: Dy TLDs show 10-20 times higher response with respect to the calculated value. In order to use LiF:Mg,Ti TLDs as a personnel dosimeter at synchrotron radiation facilities, a proper correction factor has to be incorporated in energy range below 20 keV.

Acknowledgement

The authors are thankful to Dr P D Gupta, Director, Raja Ramanna Centre for Advanced Technology for his guidance, interest and constant encouragement during the entire course of this work. The authors wish to thank to Dr S K Deb for providing guidance to carry out experiments at BL-16 of Indus-2. Authors are also thankful to Dr Tapas Ganguli and Shri A K Biswas for their valuable suggestions. They are thankful to Shri Ajit Kumar Singh for providing necessary help. They would like to thank entire operational staff of Indus accelerator for their valuable support.

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