Suitability of Topaz Glass Composites as Dosimeters Using Optically Stimulated Luminescence Technique

M. Sardar, D. N. Souza, D. P. Groppo, L. V. E. Caldas, and M. Tufail

***Abstract*—Optically stimulated luminescence (OSL) dosimetry characteristics of topaz glass composites were studied. The purpose of this research was to find the suitability of topaz glass composites as a dosimeter using the optically stimulated luminescence technique. The pellets of topaz glass from Sabser mine, Skardu, Pakistan, were prepared with dimensions of 6.0 mm diameter and thickness of 1.0 mm, and they were sintered at 900°C. Gamma, X-rays and beta doses were given to pellets from ^{60}Co/^{137} Cs, X-ray equipment (16.2 and 41.0 keV) and ^{90}Sr/^{90} Y source respectively. The OSL decay curve revealed to be exponential with a rapid decay of signal within 10 s, presenting then a non-zero long tail. There is also an exponential decay for various absorbed doses in case of beta radiation. The integrated area of OSL signal versus absorbed dose showed a linear behavior from 100 mGy to 5 Gy for gamma and X-rays. This area after irradiation with effective energies of 16.2 keV is 1.6, 3.2 and 3.3 times higher as compared to X-rays (41.0 keV), ^{60} Co and ^{137} Cs respectively. There was no significant variation in the integrated area of signal above 0.66 MeV. A maximum variation in integrated area of OSL signal of about $\pm 9\%$ was observed after ten cycles of consecutive OSL measurements. The pellets remained mechanically stable during handling in all types of experiments. Topaz glass composites can be used as dosimeters by employing the OSL dosimetry technique.**

***Index Terms*—Decay, dosimetry, effective energy, optically stimulated luminescence (OSL), reusability, Topaz.**

I. Introduction

THE increasing use and demand of radiation in many fields and processes associated with medical, sterilization, nuclear and research centre applications has motivated research on new dosimetric materials. Natural materials like Feldspars, Quartz, Calcite, Dolomite, Nepheline, Apatite, Zircon, Fluorite, Ruby, Topaz, Gypsum, Diamond, Bauxite, Ice, Magnesite, Sapphire and Anhydrite show thermoluminescence (TL) upon heating [1].

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M. Sardar is with Pakistan Institute of Engineering and Applied Sciences, Nilore, Islamabad 45650, Pakistan.

D. N. Souza is with the Departamento de Física, Universidade Federal de Sergipe (UFS), Sao Cristovao-SE, CEP, 49100-000, Brazil.

D. P. Groppo and L. V. E. Caldas are with Instituto de Pesquisas Energéticas e Nucleares, IPEN/CNEN São Paulo, 05508-000, Brazil.

M. Tufail is with Riphah International University, Islamabad, 45650, Pakistan.

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Topaz is found in late-magmatic to post-magmatic peraluminous granites and pegmatite [2]. Rich vapours of fluorine in rhyolites contribute to the formation of Topaz in volcanic settings [3]. The dosimetric characteristics can be studied for a dosimeter either by temperature stimulation (TL technique) or by optical stimulation of suitable wavelengths (Optically Stimulated Luminescence (OSL) technique).

The OSL technique has been considered a choice for many kinds of radiation dosimetry. The technique is finding extensive use in a variety of radiation dosimetry fields, including personal, environmental monitoring, geological dating and accident dosimetry, as the thermoluminescence technique. Another advantage is the possibility of OSL materials as active sensors for on-line dosimetry [4].

In the TL technique, the irradiated sample is heated to a particular temperature for the remission of the absorbed radiation [5]. However, in OSL dosimetry, light is used to stimulate the radiation-induced luminescence in natural and artificial dosimetric materials, which can then be detected using suitable apparatus. OSL occurrence is normally observed in many natural materials, and it makes OSL a promising evolving technique for applications in dosimetry [6].

The principle of OSL measurement is to stimulate an irradiated sample with light of suitable wavelength and to monitor the emission from the sample at different wavelengths. Different modes of stimulation are available, known as continuous-wave OSL (CW-OSL), linear- modulation OSL (LM-OSL) and pulsed OSL (POSL).

In CW-OSL, one uses a light of constant intensity of particular stimulation wavelength. The OSL intensity is measured instantly while excitation light and emission light is ON and usually in form of exponential-like decay. To prevent scattered stimulation light from entering the detector narrow band filters are used to discriminate between excitation light and emission light. The OSL output is monitored usually in the shape of exponential-like decay until all traps are emptied, and the luminescence ceases. The integrated OSL emission (i.e., area under the decay curve, minus background) is recorded and is used to determine the dose of absorbed radiation. In numerous cases the decay curve may be exactly exponential or may be the sum of several exponentials. In certain cases the OSL signal is observed to increase initially before decay. This wide variety of OSL decay curve shapes depend upon multiplicity of possible recombination pathways and processes for the production of OSL [7].

In LM-OSL, stimulation light is increased linearly with time, and the output is measured which increases linearly initially as the stimulation power is increased until the traps become depleted; thereafter the OSL intensity decreases non-linearly to zero. The stimulation source in POSL is pulsed at a suitable modulation frequency, and OSL emission is observed only between the pulses rather than during the pulses [4].

The OSL technique presents several advantages over the conventional TL technique. The most interesting is that in OSL the stimulation source is optical, requiring no heating of the samples.

It is the first study on natural mineral Topaz of Sabser mine near Skardu as far as OSL dosimetry is concerned.

II. Materials and Methods

The samples of Topaz were collected from Sabser mine (SM) in the neighbourhood of Skardu, Pakistan. The crystal size of the Topaz samples varied from 1.5 to 3.5 cm. The crystals of Topaz were cleaned with 50% water and 50% Aqua Regia ($3HCL+HNO_3$) solution to remove the dust/dirt and particles of other minerals/ores associated with the lumps of Topaz. The crystals of Topaz were converted into powder of particle size of 50 to 75 μm. Silica glass was also converted in to powder of the same particle size. The same composites were used by Souza *et al.* (2003) to study TL characteristics. Topaz powder (2 wt (%) and glass (1 wt (%)) were mixed uniformly to form the Topaz glass composites [8]. Pellets with dimensions of diameter 6.0 mm and thickness 1.0 mm were made by applying pressure of 120 kgf/cm^2 using hydraulic press. These pellets were sintered at various temperatures; it was observed that with increase of the sintering temperatures, the TL response decreases and the mechanical stability of the pellets increases. The optimum sintering temperature 900°C for the time of one hour was selected.

Samples of Topaz glass composites were irradiated with gamma rays from ^{60}Co (348.207Ci, Model: F1S60-04, Panoramica, Japan), ^{137}Cs (740 MBq, Model: CI-STS, Type OB 85/1, Germany) calibrators; X-rays equipment with effective energies 16.0 and 41.0 keV (potential 150 kV, 20 mA, Model: Pantak Seifert, Germany) and beta particles using a ^{90}Sr/^{90}Y source (calibrated by Physikalish-Technische Bundesanstalt, Germany).

In all irradiations, the samples of Topaz glass composites were wrapped in non-transparent black paper during and after irradiations until the measurements, to protect the samples from phototransference of charge which may be induced by visible light. All irradiations and measurements were performed at room temperature. OSL signals were read within 24 hours after each irradiation.

A RisØ TL/OSL reader (Denmark) was employed for OSL measurements. Only two light stimulation sources such as infrared (IR) with wavelength in the range of 800–900 nm and blue LEDs (470 nm) are available in the RisØ TL/OSL reader. The IR can stimulate the luminescence from most feldspars but not for quartz at room temperature [9], so it was not possible to stimulate the luminescence for Topaz glass samples with IR source. The other stimulation source was the blue LEDs (NICHIA type NSPB-500AS) as the excitation source with peak emission at 470 nm (FWHM = 20 nm). The light sensitive component of the reader was the cathode, and the photomultiplier (PMT) in the RisØ TL/OSL instrument was a Bialkali EMI 9235QB PMT, which presents detection efficiency between 200 and 400 nm. This feature makes it suitable for detection of luminescence from both quartz and feldspars. Moreover, the quantum efficiency of the PMT is maximum for the luminescence wavelength 200–400 nm. Therefore blue LEDs were used for stimulation of the Topaz glass samples. The OSL signal was measured using the continuous wave-optical stimulated luminescence (CW-OSL) mode. Detection filters U-340 were used during these measurements.

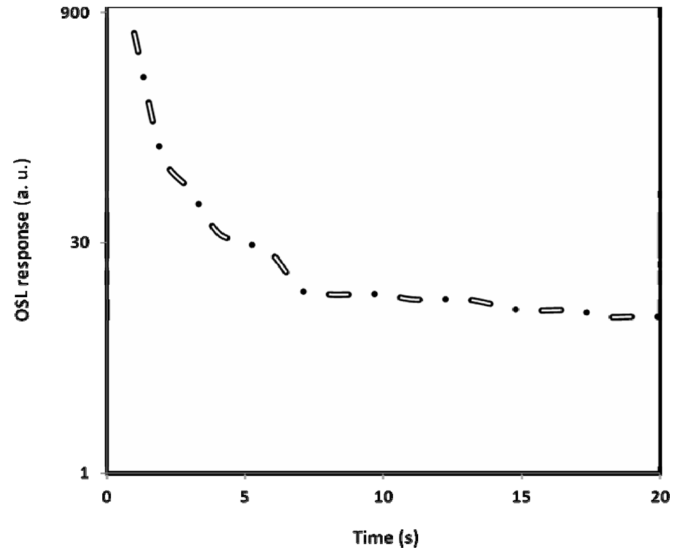

Fig. 1. CW-OSL behavior of Topaz: glass composite (2:1 (wt (%)) of SM of Skardu, Pakistan of exposed to 5.0 Gy of ^{60}Co gamma radiation.

III. Results

The samples of Topaz glass composites were irradiated with ^{60}Co at an absorbed dose of 5 Gy to study the continuous wave-optical stimulated luminescence (CW-OSL) behavior. The samples were excited with blue LEDs during 20 s which produce an almost exponential decay signal for all absorbed doses as presented in Fig. 1.

Initially the decay is very rapid, and after 10 s it seems completely depleted; thereafter a long non-zero tail was observed. According to Mckveer (2001), this long non-zero tail is caused by shallow or deep traps [7]. The shallow traps, in which the stimulated charge becomes temporarily trapped, are slowly released over the time scale of the experiment. Another reason is in case of the deep traps for which the photoionization cross-section is small at the wavelengths used in the measurement, deep trap emptying is slow.

Moreover, according to Mckveer (2001), the shape of the CW-OSL decay curve is not necessary exponential and does not provide itself to simple description [7]. He investigated that CW-OSL decay curve shape or pattern is dependent upon the sample, the absorbed dose, the wavelength of stimulation, the stimulation intensity and the sample temperature.

The CW-OSL behavior of Topaz: glass composite (2:1 (wt (%)) of SM for various absorbed doses irradiated with the beta source (^{90}Sr/^{90}Y) and measured with the OSL technique is presented in Figs. 2 and 3. In Fig. 2 we can see that the curves at all

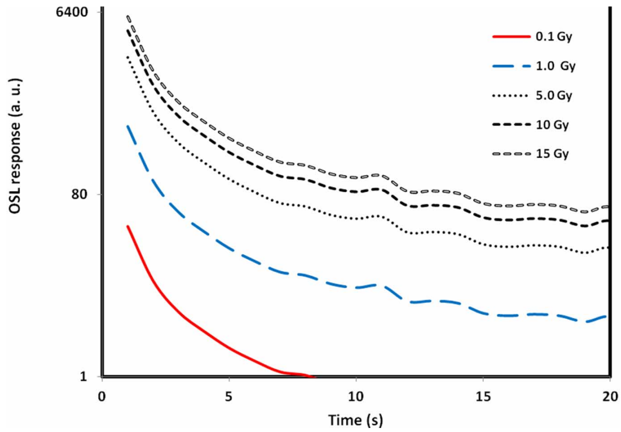

Fig. 2. CW-OSL behavior of Topaz: glass composite (2:1 (wt (%)) of SM for exposed to various absorbed doses from beta radiation source.

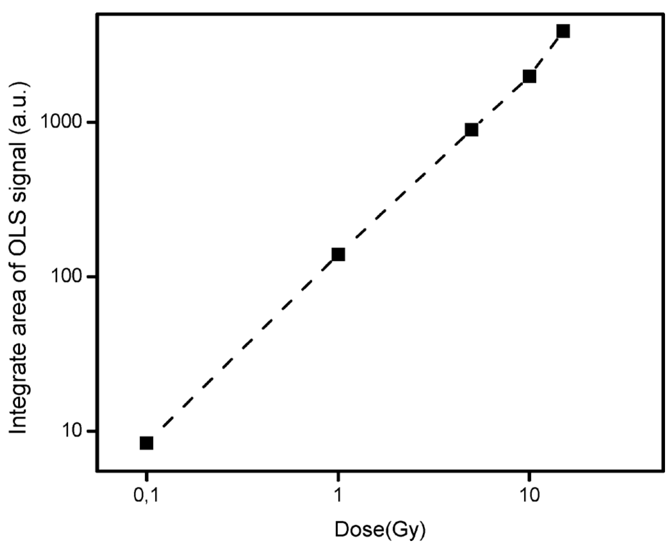

Fig. 3. Linearity behavior of Topaz: glass composite (2:1 (wt (%)) of SM for absorbed doses of 0.1 to 15.0 Gy, irradiated with beta source.

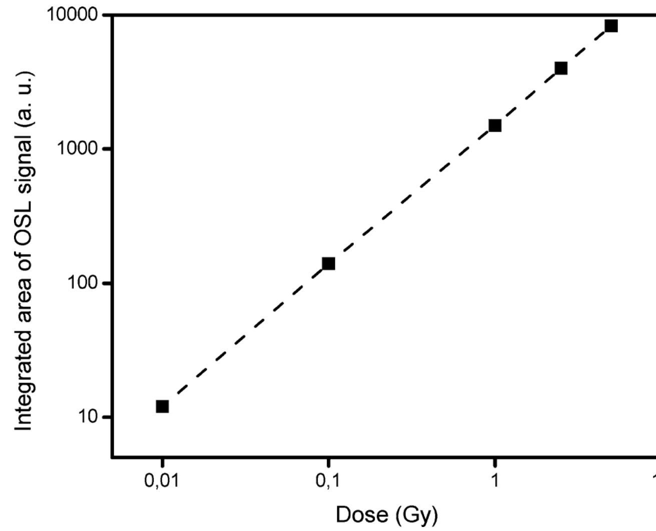

Fig. 4. Linearity behavior of Topaz: glass composite (2:1 (wt (%)) of SM, Pakistan, for absorbed doses of 0.01 to 5.0 Gy, irradiated with X-rays (16.2 keV).

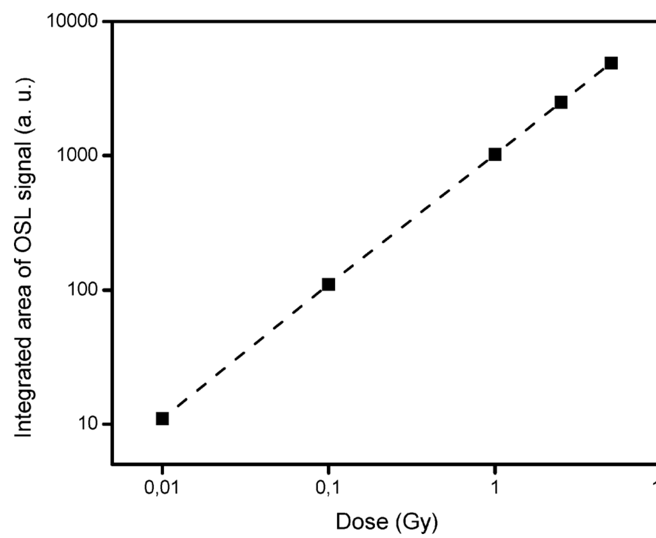

Fig. 5. Linearity behavior of Topaz: glass composite (2 : 1 (wt (%)) of three mines of Skardu, Pakistan, for absorbed doses from 0.01 to 5.0 Gy, irradiated with X-rays (41.0 keV).

absorbed doses from 0.1 Gy to 15 Gy present exponential decays. In both figures it is observed that with increasing absorbed dose the initial values of the OSL signal also increase.

Comparing the OSL intensities of the Topaz: glass of SM with results shown by Al_2O_3:C commercial samples produced by Landauer Inc. [10], [11] it was possible to observe that the OSL intensity of our samples exhibit a slight gain. For 10 Gy of beta radiation the OSL response of Topaz: glass samples is approximately 12 times more intense than for 1 Gy, while the Al_2O3:C chips [10] and the dot dosimeters [11] show an increased intensity equivalent to 7, 5 and 9, respectively.

The Topaz: glass composites were irradiated with gamma (^{60}Co) and X-rays (effective energies 16.2 and 41.0 keV) with the absorbed doses of 0.01 Gy to 5 Gy. After the irradiation, the samples were exposed in laboratory to a steady source of light and a suitable wavelength of 470 nm. The integrated area of the OSL signal from Topaz mineral i.e., the area under the decay curve is recorded for various known absorbed doses, and is presented in Figs. from 4 to 7 respectively.

Through the calibration curve of integrated OSL signal against the known doses of radiation, the unknown absorbed dose can be measured from these curves. The integrated OSL signal *of* Topaz samples increased linearly with the dose level between 0.01 Gy and 5 Gy for all gamma and X-ray irradiation sources. The integrated area of OSL signal for the X-rays with effective energies of 16.2 keV and 41.0 keV was found about 2.0 and 1.5 times more as compared to sample irradiated with ^{60}Co. This linearity is a good reason to apply this material for dosimetry at radiotherapy and sterilization centres using OSL dosimetry.

Topaz: glass composites were irradiated with gamma rays (^{60}Co & ^{137}Cs) and X-rays (16.2 keV and 41.0 keV) with the absorbed dose of 1.0 Gy to study the OSL response curve under the same parameters of irradiation and OSL read-out. The luminescence stimulated due to the light from composites was monitored as a function of stimulation time. The OSL curves are shown in Fig. 6. The behavior of OSL curves under various irradiation fields was also found to be an exponential decay and

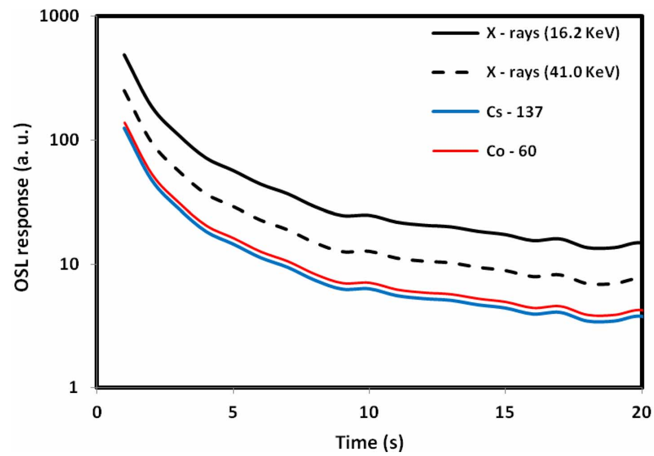

Fig. 6. CW-OSL behavior of Topaz: glass composite (2:1 (wt (%)) of SM for an absorbed dose of 1.0 Gy, irradiated with different irradiation sources.

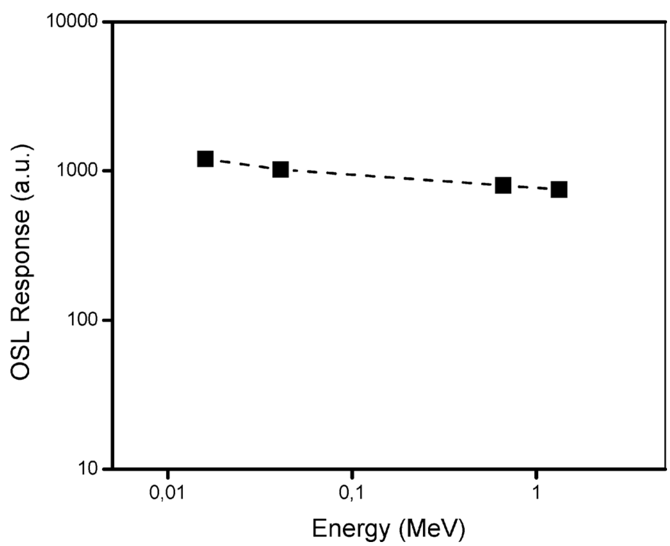

Fig. 7. Energy dependence of OSL response of Topaz:glass composite (2:1 (wt (%)) of SM for an absorbed dose of 1.0 Gy, irradiated with photons.

the initial decay was rapid within 10 s. The initial OSL signal showed high response for X-rays as compared to ^{137}Cs and ^{60}Co. However, OSL initial signals for ^{60}Co and ^{137}Cs were almost similar.

The energy dependence of OSL signal for the Topaz: glass composites is shown in Fig. 7. The OSL response for X-rays with the effective energy of 16.2 keV is 1.6, 3.2 and 3.3 higher as compared to X-rays of 41.0 keV, ^{60}Co and ^{137}Cs respectively. There was no significant variation in the integrated area of OSL signal observed above energy of 0.66 MeV. Energy dependence is not a desirable dosimetric behavior, but has been observed even for commercial dosimeters [10].

Reproducibility denotes to an ability of a dosimeter to accurately reproduce or replicate its response at the same annealing temperature, irradiation dose, and OSL read-out [12]. The reproducibility of a pellet was checked for its reuse after a cycle of irradiation and measurement. Topaz chips of Sabser mine were annealed for one hour, irradiated with gamma rays from ^{60}Co for the absorbed dose of 1.0 Gy, and the integrated area of OSL

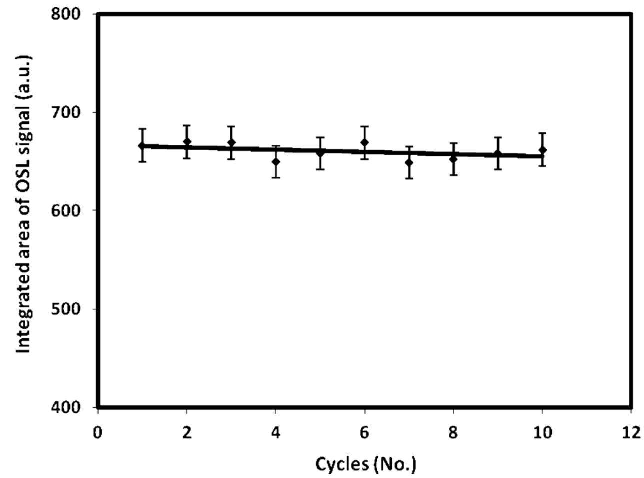

Fig. 8. Reproducibility behavior of Topaz: glass composite (2 : 1 (wt (%)) of SM initially irradiated with an absorbed dose of 1.0 Gy (^{60}Co).

was monitored. The experiment was repeated up to ten cycles under the same parameters and conditions. The integrated area of OSL signal of every cycle was observed noted. Up to ten cycles, the behavior of integrated area of OSL signal is shown in Fig. 8. A maximum OSL variation of about ±9% was observed during each ten cycles of measurements by drawing a trend line of measured integrated OSL signals. Whereas the uncertainties associated with the measurements of each cycle were in the same range, this result can be considered good. The reproducibility of the Topaz: glass composites using the OSL technique is another reason to apply these composites as radiation dosimeters.

About 100 pellets of Topaz: glass composites of standard size were prepared to execute different experiments for the study of OSL features of Topaz samples. In all these experiments, the chips were annealed, irradiated and measured using the OSL technique several times. Topaz chips remained intact during mechanical handling, therefore mechanical stability of Topaz as an OSL detector was insured for the study of the samples. This property also favours the Topaz for its use as dosimeters for application in dosimetry using OSL technique.

IV. Conclusion

The OSL decay curves for absorbed doses of 0.1 Gy to 5 Gy with different irradiation sources showed that there is an exponential with rapid decay of signal and then a non-zero long tail. The initial signal height of OSL curve roses linearly with increase of the absorbed dose in case of beta particles irradiation. The integrated area of OSL signal versus absorbed dose (calibration curve) showed a linear behavior with absorbed dose between 0.1 Gy and 5 Gy for all gamma and X-ray irradiation sources. The integrated area of OSL signal for X-ray with effective energy of 16.2 keV is 1.6, 3.2 and 3.3 is higher as compared to X-rays (41.0 keV), ^{60}Co and ^{137}Cs respectively. There was no significant variation in the integrated area of OSL signal above the energy of 0.66 MeV. The maximum OSL change of about ±7% to ±9% was observed between the 1st cycle and the 10th cycle. The pellets remained mechanically stable during handling in all types of experiments. Topaz glass composites in the form of pellets can be efficiently used as dosimeters after applying the suitable calibration factor to the measured integrated area of OSL signal to assess the accumulative absorbed dose.

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