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Mapping radiation fields in containers for industrial γ-irradiation using polycarbonate dosimeters

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A B S T R A C T

The main part of the quality control of industrial irradiation is assurance of absorbed doses in various parts of irradiated objects. Commercial polycarbonate (PC) films develop yellow color upon radiation exposure. PC films (3 mm thick) were used to map radiation fields inside product containers irradiated with Co-60 sources at IPEN. Optical densities were measured with a Shimadzu UV2101PC spectrophotometer.

1. Introduction

Due to the progress in radiation chemistry, ionizing radiation is now widely used to improve quality of products. Many areas have benefited from this technique, such as medicine (therapy and diagnostics), industry (sterilization of medical products and food, as well as polymerization and reticulation), and agriculture (Radiation Technology Center, 2007).

Dosimetry systems used to monitor radiation-based technologies must be able to provide precise and accurate dose responses in the desired dose ranges. It is essential that the product would not receive an absorbed dose lower or higher than the values specified for the procedure (McLaughlin and Desrosiers, 1995).

A wide variety of polymeric materials are used in dosimetry, such as cellulose triacetate, nylon, polyester, fluoropolymer, and polymethyl methacrylate. Radiation induces changes in such materials, the nature of which depends on the substrate composition and a presence of a dye in the material (Bhattacharya, 2000; Galante and Campos, 2006, 2008, 2010; Galante et al., 2004, 2010).

Commercial polycarbonate (PC) is a new type of film dosimeters. Under irradiation, it develops yellow color, the intensity of which is suitable for measuring high γ-doses (Chung, 1997; Galante and Campos, 2010; Kumar et al., 2006; Sinha et al., 2004; Sharma et al., 2008).

The goal of this work was to check if PC films can be used to measure doses to irradiated products in industrial irradiation plants. PC films (3 mm thick) were used to map dose fields inside containers for γ-irradiation of products. The irradiations were performed at CTR/IPEN with a Gammacell 220 (a large, 3.7-L irradiation chamber with Co-60 sources doubly encapsulated in stainless steel tubes and held in a source cage in lead shielding) and with a panoramic Co-60 source (metallic Co-60 pencils encapsulated in stainless steel, stored in a source cage in lead shielding, Fig. 3).

2. Materials and methods

Film pieces (3×1 cm^2) were cut from commercial 2×1 m^2 sheets of PC.

Two experiments were performed: one with a Co-60 Gammacell 220 and the other with a Co-60 panoramic source.

In the Gammacell experiment, two thin-wall coaxial cylinders of different diameters held the dosimeters spread over the irradiation area (Fig. 1). These two cylinders were placed inside a cylindrical plastic container (d=11 cm; h=15 cm; wall thickness=1 mm) and the empty space was fulfilled with powdered gelatin to simulate a product to be irradiated. A nominal dose 30 kGy was given to the package.

In irradiations with the panoramic source, the PC dosimeters were spread inside a rectangular container (l=33 cm, w=19 cm, h=12 cm) (Fig. 2). The distances from the source to the dosimeters ranged from 10 to 40 cm (Fig. 3). The nominal absorbed doses were between 9.73 and 69.7 kGy.

Optical densities of the films were measured with a Shimadzu UV2101PC spectrophotometer at 412 nm (absorption maximum) 1 h after the irradiation. Each presented value is the average of five measurements, and the error bars represent single standard deviations of the means.

3. Results and discussions

Absorbed doses to the 66 detectors in the container irradiated in Gammacell were measured using the calibration curve shown in Fig. 4. The doses varied between 22.7 and 41.0 kGy, Fig. 5. The lower doses were observed at the bottom of the chamber in the

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Fig. 1. Arrangement of the PC dosimeters for field mapping in the cylindrical container in Gammacell 220.

Fig. 2. Arrangement of the PC dosimeters for field mapping in the parallelepiped container irradiated with the panoramic Co-60 source.

inner circle of the dosimeters (3 cm from the container wall). The highest dose (41.0 kGy) was found at 15 cm from the bottom of the chamber.

The results show that the radioactivity distribution around the irradiation compartment is not homogeneous, which results in the coefficient of variation of the dose of 15% over the whole volume. This variation is significant because the uncertainty of the nominal dose in industrial irradiations combined with the uncertainties of routine chemical dosimetry is approximately 8% (McLaughlin et al., 1989; Miller, 1993).

Fig. 6 shows variations of the responses of the dosimeters irradiated in the panoramic source. The responses are normalized to the response of the dosimeter located in position *P1* (Fig. 3), which was 10 cm far from the source. The results agree with the increasing source–dosimeter distance, i.e., generally, the farther a dosimeter is located from the source, the lower is its dose.

As the configuration of the container (parallelepiped) differed from the configuration of the radiation field (sphere), harmonic interpolations were performed to determine the dose rates in the positions of the dosimeters. The container's vertexes were located

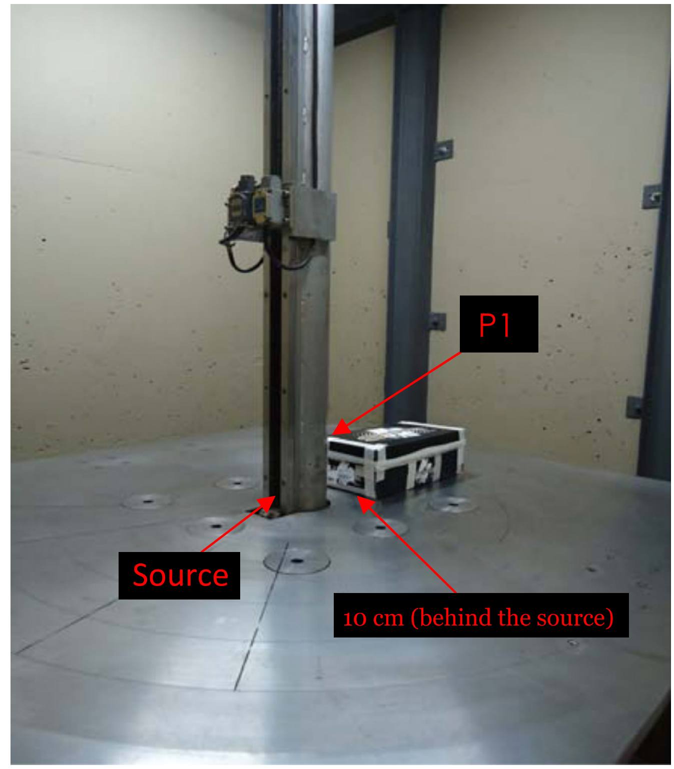

Fig. 3. Setup for irradiation of the parallelepiped container with PC dosimeters using the panoramic source. *P1* is the position of the dosimeter whose response is taken for unity in the normalization.

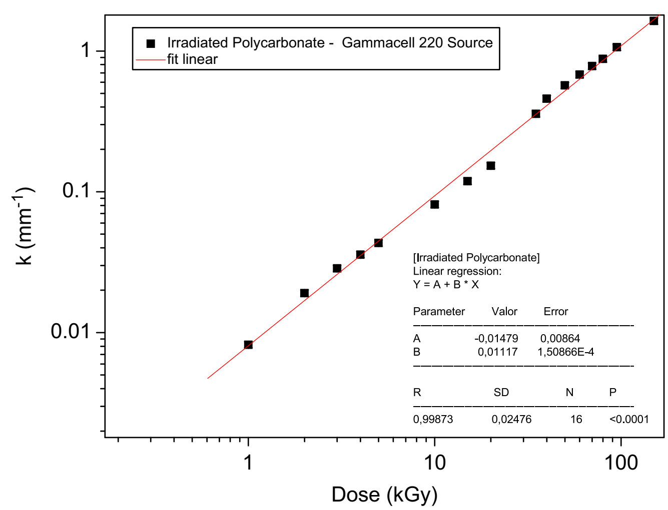

Fig. 4. Dose response curve of the PC dosimeters. Irradiation in Gammacell 220. λ=412 nm.

exactly on the circle with a radius of 10 cm (Fig. 3), and, as a result, the geometric center of the front face of the container was only 7 cm far from the source. Accordingly, the dose rate in the geometric center was higher.

Table 1 shows dose rates at the distances of 7, 18.2, 28.7, and 39.1 cm from the source obtained by interpolation of the dose rates at the distances of 10, 20, 30, and 40 cm, respectively from the source known from certified calibrations. The decrease in the dose rate was expected because of the growth of the distance and attenuation by gelatin.

The measured dose distribution agrees with the isodose map provided by the manufacturer of the radiation source within 5%.

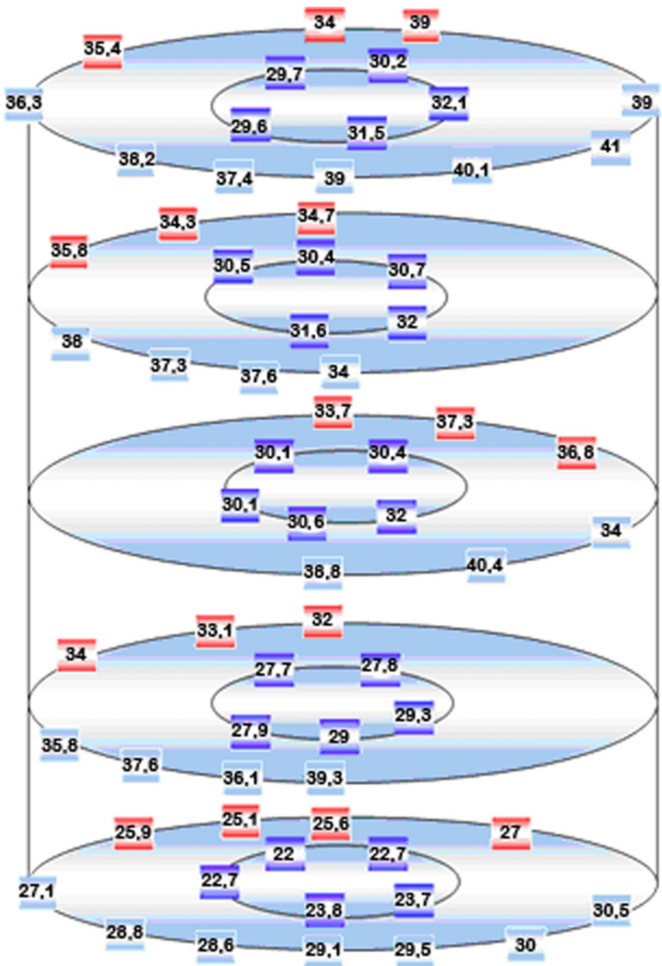

Fig. 5. Absorbed dose map in the cylindrical container irradiated in Gammacell 220.

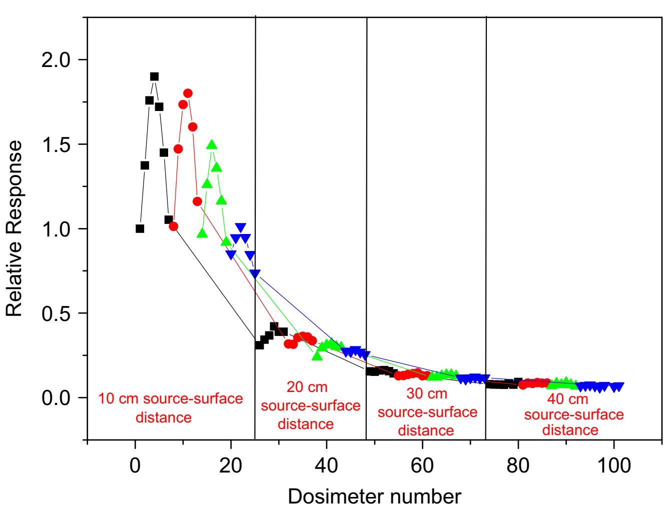

Fig. 6. Relative responses of the PC dosimeters irradiated in the parallelepiped container with the panoramic source. Distance from the table: ■—10 cm; ●—7 cm; ▲—3 cm; ▼—1 cm.

4. Conclusions

PC detectors are easy to prepare and use, and they are inexpensive. The intensity of the stable color developed under irradiation can be measured spectrophotometrically at 412 nm. The optical density is proportional to the absorbed dose, and the material can be used as a radiation dosimeter for quality control.

Like in the case of other secondary dosimeters, it is necessary to calibrate the polycarbonate films against a reference dosimeter under the same conditions.

PC dosimeters are highly sensitive and can be used to characterize dose distribution in irradiated products, which is necessary for measuring maximal and minimal doses delivered in radiation processing.

Table 1
Nominal and interpolated dose rates at various distances from the panoramic source.

Distance (cm)	Dose rate (kGyh^{-1})	Relative value (%)	Dosimeter response (K cm^{-1})
Nominal values			
10	0.1612	100.00	0.284
20	0.0645	40.01	0.097
30	0.0373	23.14	0.040
40	0.0225	13.96	0.023
Results of interpolation			
7.0	0.2527	100.00	0.527
18.2	0.0767	30.37	0.117
28.7	0.0402	15.91	0.045
39.1	0.0238	9.40	0.021

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