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Comparison of dichromate and ethanol-chlorobenzene dosimeters in high dose radiation processing

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Abstract. Dichromate and ethanol-chlorobenzene dosimeters were studied in conditions of annual temperature changes during process control at the Radiation Unit of the Vinča Institute. Measurements were performed in February (10–14°C) and August (22–35°C) for the dose range 10–50 kGy. The difference between measurements using these dosimeters is in agreement with the previous laboratory studies of temperature effect on the dose response of a dichromate dosimeter. The absorbed doses measured by these two dosimeters are in good agreement and the difference is within a limit of 3% for the studied dose range. The uncertainties of dose measurements using dichromate dosimeter arising from irradiation during annual temperature changes appear to be well within acceptable limits indicating that this dosimeter can be used as a routine dosimeter.

Key words: radiation processing • cobalt-60 • ethanol-chlorobenzene • dichromate • dosimetry

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Introduction

Radiation processing in many areas, particularly in radiation sterilization, demands control of the absorbed dose. Many dosimeters have been proposed for the high-level dose range (region of 10 to 50 kGy). However, in addition to the required reproducibility, reliability or uncertainty (< 5%), it is desirable for radiation processing that the selected dosimetric system is easy to operate. One of those "easy-to-use" high dose dosimeters is the ethanol-chlorobenzene (ECB) dosimeter but only when the measurement of doses is done by oscillometric readout and not when high precision is needed which requires titration of chloride ions formed by irradiation [2].

The dichromate dosimeter is now a well known dosimetric system whose preparation is standardized [4]. It is used as a reference/transfer dosimeter by virtue of its excellent stability and reproducibility. Preparation and measurements can be characterized as "easy-to-use". Considering these characteristics, the dichromate dosimeter seems to be a good candidate for use in radiation processing as a routine as well as a reference/transfer dosimeter. However, the dichromate dosimeter shows the irradiation temperature dependence which could present a problem in measurements of absorbed doses for varying conditions of irradiation in radiation processing. The irradiation temperature dependence was studied earlier [6], but the verification of consistency of those results in real conditions of irradiation in radiation processing needs further investigation.

The present study investigates characteristics of both dosimeters, the ECB and dichromate dosimeter, in conditions in radiation processing at the Radiation Unit of the Vinča Institute during one year.

Materials and methods

The Radiation Unit of the Vinča Institute has been described in more detail elsewhere [7], and only a brief description will be given here. The source frame is loaded with 5.55×10^{15} Bq of ^{60}Co with the source rods occupying predominantly the central part of the frame (1 × 3 m). An automatic conveyer carries boxes through the source. One irradiation run consists of four sequential irradiation cycles, and in each cycle a given box passes through the irradiation room at one of four vertical levels, i.e. every box is irradiated in the same way.

The ECB and the dichromate dosimeters were prepared in accordance with the procedures described in corresponding standards [2, 4]. Both dosimeters were placed in 2 ml glass pharmaceutical ampoules and flame-sealed. Two ampoules with an ECB solution and three ampoules with a dichromate solution were put together in the standard cardboard boxes filled with products for irradiation. The dosimeters were placed in the central part of the box at the minimum dose position. The boxes with dosimeters were irradiated with doses between 10–50 kGy. We analyzed doses at two temperature extremes: summer and winter. The temperature was measured in and out of the irradiation room. In the irradiation done in February, the temperature was between 10–14°C, and between 35–22°C during irradiation done in August, due to the larger day/night variations.

The absorbed doses of the ECB dosimeters were measured by an oscillotitrator OK-302/2. The response of the oscillotitrator was calibrated at 25°C in accordance with ISO/ASTM 51538 [2] using the calibration series of the same batch of ampoules with the ECB solution that had been irradiated by known doses in well-defined conditions. The calibration diagram was obtained as a second order polynomial fit for doses between 10–35 kGy and is presented in Fig. 1. The absorbed doses over the calibration range were measured using two sets of ECB dosimeters and the values of doses for two irradiation cycles (e.g. 2 times 25 kGy) were accumulated.

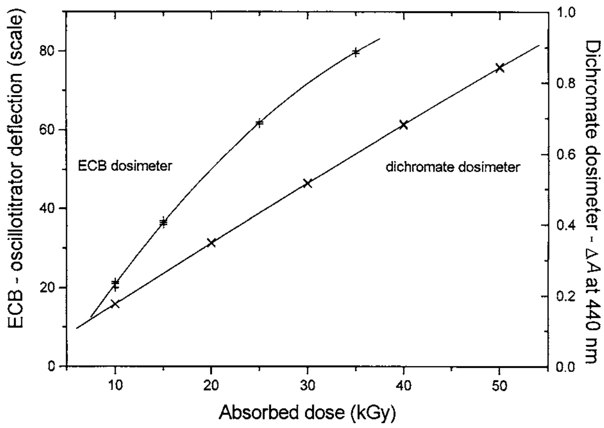

Fig. 1. The calibration diagram for the ECB dosimeter (the relation of the absorbed dose and the response of the oscillotitrator, $n = 3$) and the dichromate dosimeter (the net optical absorbance, ΔA, was measured at 440 nm and at 25°C, $n = 3$).

The dichromate dosimeters were measured at a temperature of 25°C, using the spectrophotometer Perkin-Elmer Lambda 5 at a wavelength of 440 nm. The net optical absorbance (ΔA) was calculated as the difference in optical absorbance values of the unirradiated and irradiated dosimetric solutions. The calibration curve was obtained by irradiating dichromate dosimeters from the same batch with the standard source at 25°C and the calibration diagram is presented in Fig. 1.

Results and discussion

Table 1 presents the results obtained for ECB and dichromate dosimeters irradiated in the Radiation Unit in February and August. Uncertainties were calculated according to [1, 3, 8].

For the ECB dosimeter, the standard uncertainty in the preparation of the calibration function was 3%. The standard uncertainty due to the oscillometric reading for different ampoules irradiated with the same dose was at most 3% (for higher doses the relative uncertainty decreases). The standard uncertainty due to reading

Table 1. Absorbed doses of dichromate measured by spectrophotometer at $\lambda = 440$ nm (the presented results are the average readings of three measurements with their standard deviations) and ECB dosimeters measured by oscillotitrator (the presented results are the average readings of ten measurements for each ampoule with their standard deviations)

	Absorbed dose measured by dichromate dosimeters (kGy)	Absorbed dose measured by ECB dosimeters (kGy)
February	10.5 ± 0.2	10.3 ± 0.1
	20.6 ± 0.1	20.2 ± 0.3
	26.9 ± 0.1	26.7 ± 0.3
	32.2 ± 0.1	31.8 ± 0.6
	37.0 ± 0.1	37.3 ± 0.4
	52.0 ± 0.1	52.3 ± 0.8
August	12.7 ± 0.3	12.5 ± 0.2
	25.1 ± 0.1	25.2 ± 0.3
	25.6 ± 0.1	26.0 ± 0.4
	31.1 ± 0.1	31.4 ± 0.3
	37.3 ± 0.1	38.0 ± 0.2
	49.5 ± 0.1	50.8 ± 0.5

by the oscillotitrator for the same ampoule was 2%. Hence, the combined standard uncertainty of measurements by the ECB dosimeter was 4.7% at most.

Results presented in Table 1 for the dichromate dosimeter show that the measurements below 20 kGy have a somewhat higher deviation than for doses ≥ 20 kGy. This is inherent to the spectrophotometric procedure since the doses are calculated from net absorbance (ΔA), calculated as the difference between absorbance of unirradiated and irradiated dichromate solutions. The measured absorption value of the unirradiated solution was $A_0 = 1.109 \pm 0.004$. For low doses the net difference is small and the absolute error of 0.004 is the 2% relative error for $\Delta A = 0.2$, but is less than 0.5% for ΔA around 0.85 (50 kGy). Taking this into the calculation, the combined uncertainty of the dichromate dosimeter was 3.6%, where 3% originated from the standard uncertainty in the preparation of the calibration curve and 2% from the standard uncertainty due to measurement of absorbance. This is significantly lower than for the ECB dosimeter, which is not surprising since the measurements by the spectrophotometer are more precise than the oscillotitrator measurements. However, irradiation temperature cannot always be controlled in radiation processing. Hence, if we add the uncertainty of around 2.3%, that should arise from the temperature effect [6], the overall uncertainty should be around 4.3%, which is not much lower than for the ECB dosimeter.

The results obtained for dichromate and ECB dosimeters are compared and presented in Fig. 2 as the relative response of dichromate and ECB dosimeters $(D_{dich} - D_{ECB})/D_{ECB}$ irradiated together in the Radiation Unit. The dose obtained by ECB was taken as a reference, despite larger uncertainties of measurements, since the dose response of ECB is independent of the temperature during irradiation in the examined range of temperatures [2, 5]. The results show that absorbed doses measured by dichromate dosimeters in February are higher than measurements made by the same dosimeters in August, irrespective of the dose. This is in agreement with the previous study of the effects of temperature during irradiation of dichromate dosimeters showing that net absorbance decreases with the increase of the irradiation temperature for the same absorbed dose [6]. The maximum difference February/August is around 2.5%, which is in agreement with the temperature coefficient of dichromate dosimeters measured in laboratory conditions [6].

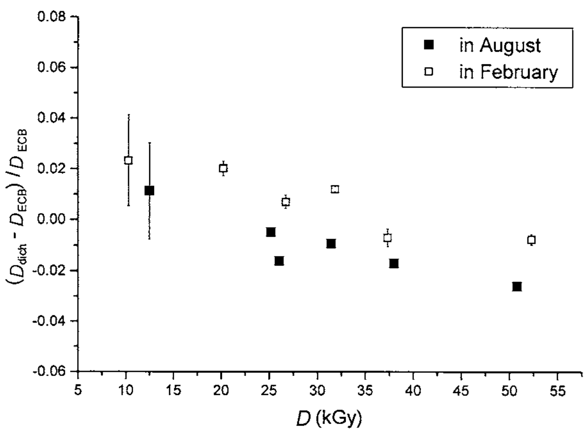

Fig. 2. The relative response of dichromate and ECB dosimeters $(D_{dich} - D_{ECB})/D_{ECB}$ irradiated together in the Radiation Unit: □ – in February; ■ – in August. The standard deviation is given by a vertical bar for those deviations that are larger than the dimension of symbols.

As can be seen in Fig. 2, the difference $(D_{dich} - D_{ECB})/D_{ECB}$ between measured doses by these two types of dosimeters is within the limit of 3% in the studied dose range. It is common in radiation processing that the acceptable differences of dose measurements between two dosimetric systems is up to 5%. This indicates very good agreement between measurements made by dichromate and ECB dosimeters. Slightly higher deviations of results for doses below 20 kGy statistically increase the difference to around 4.3%, which is still within acceptable limits.

Results in Fig. 2 also show that there exists a dose dependence of $(D_{dich} - D_{ECB})/D_{ECB}$ which seems to be independent of the irradiation temperature, since the slope is roughly the same for both irradiation temperatures. This is likely to be connected with the dose effect on $G(Cl^-)$ [5], but it is not possible to perform a detailed analysis using routine measurements of doses in the processing unit.

In conclusion, the obtained results for ECB and dichromate dosimeters show that both can be used in radiation processing as routine dosimeters. When dichromate dosimeters were used as routine dosimeters, the overall uncertainties of dose measurements arising from irradiation during annual temperature changes appear to be well within acceptable limits.

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