9.3 Dosimetry Study for Electron Beam Irradiation in Radiation Processing

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Abstract For certain critical applications such as medical device sterilization and food irradiation, accurate calibration of electron energy and absorbed dose is required to assure the quality of irradiated products. To meet this requirement, TRCRE, JAERI has carried out research and development on high dose radiation dosimetry for electron beams in the energy range used in radiation processing (0.15 - 3.0 MeV). JAERI has developed a simultaneous electron beam energy and dosimeter calibration system that consist of a total absorption calorimater, an electron current density meter, and a stacked thin-film dosimeter set.

For low energy electrons, where it is important to measure the depth-dose profile in materials with high depth resolution, we studied the feasibility of a method using Gafchromic film dosimeters. This film, which has an 8-μm thick sensitive layer, is combined with a stepped array of absorber films of the same thickness to produce a high-resolution depth-dose profile on the Gafchromic film. The depth-dose profile obtained in this manner has about five times greater resolution than conventional radiochromic film dosimetry.

INTRODUCTION

Studies of radiation processing using electron beams have been carried out widely at Takasaki Radiation Chemistry Research Establishment (TRCRE), JAERI using three accelerators that cover the energy range from 0.15 to 3.0 MeV. For R & D studies of radiation processing, it is very important to establish reliable dosimetry methods because absorbed dose measurements are necessary to compare radiation effects quantitatively. Also, in industrial applications, accurate dose evaluation is necessary to ensure the quality of the process.

Dosimetry studies in radiation processing, including dose distribution measurements using film dosimeters and a calibration system for secondary routine dosimeters, have been reported in a previous publication (Tanaka et al., 1985). This study reports on a new method to simultaneously measure electron energy and calibrate the response of routine dosimeters. We also describe a method for obtaining high-resolution measurement of the depth-dose distribution of low-energy electrons.

SIMULTANEOUS CALIBRATION SYSTEM FOR ELECTRON ENERGY AND ROUTINE DOSIMETERS

Electron beam radiation processing requires reliable measurement of absorbed dose in order to satisfy regulatory and quality control requirments. This demands periodic calibration of the response of dosimeters and the measurement of electron energy.

We have developed a simple system for simultaneous measurement of electron energy and calibration of routine dosimeters for medium energy (1 - 5 MeV) electron beam irradiation (Tanaka et al., 1991). The system consist of a total absorption calorimeter, an electron current density (ECD) meter (Tanaka et al.,1980) and a stack of un-calibrated film dosimeters with sufficient thickness to cover the electron range of interest. The same electron fluence is given to each by moving the three detectors across the irradiation zone

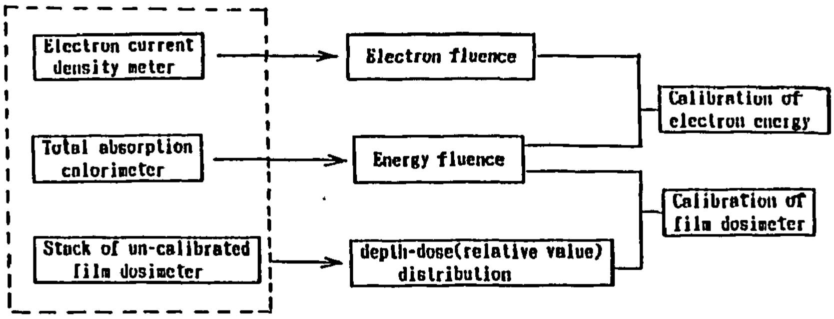

Fig.1 Schematic diagram of the simultaneous calibration system.

of the electron beam simultaneously or successively. Each detector experiences the exact same energy fluence, electron fluence and depth-dose (in relative value) profile, respectively. Figure 1 shows a schematic diagram of the system. For calibration of electron energy, the energy fluence (J/cm^2) and electron fluence (cm^{-2}) are combined,

$$E = 10^{6} \cdot \frac{\psi_0}{\phi_0} \cdot \frac{1}{e} \qquad (1)$$

where E is the mean energy of the electrons in MeV, $e = 1.602 \times 10^{-19}$ is the charge of per electron, ψ_0 (J/cm^2) is the measured electron energy fluence corrected for energy backscattering and radiation loss, and ϕ_0(cm^{-2}) is the electron fluence corrected for number of electrons backscattered.

The electron energy obtained in this manner is the mean energy of the electrons that enter the detectors. Therefore, this method is particularly well adopted to the measurement of the electron energy of dc accelerators in which the energy spread is low.

In addition to the energy measurement, routine film dosimeters are simultaneously calibrated by combination of energy fluence and depth-dose (in relative value) distribution data. Especially, for the dosimeters which have linear relation between the absorbed dose and change in optical density, such as CTA film dosimeter, the calibration can be carried out using the following relation simply.

$$K = \frac{t \cdot \Sigma(\Delta OD_i)}{\phi_0} \quad (2)$$

where

K : response of the film dosimeter, K-value, change in optical density per unit dose $(kGy)^{-1}$

t : thickness of a film dosimeter (g/cm^2),

ΔOD_i : change in optical density for each film,

Performance of the total absorption calorimeter has been tested to determine effects of different materials and chamber size (Sunaga et al., 1995). Figure 2 shows the

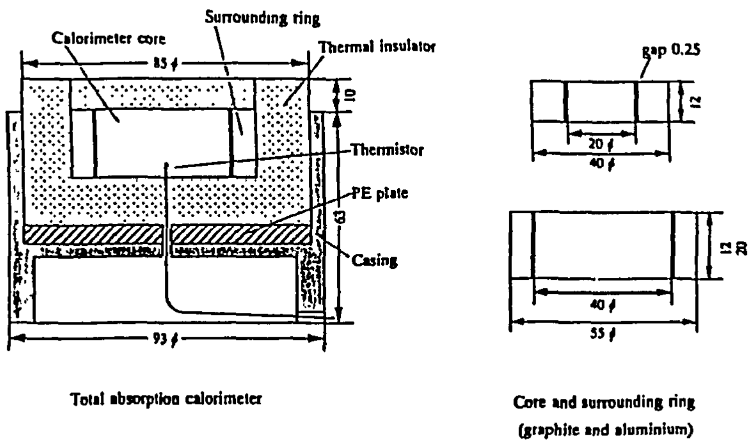

Fig.2 The cross-sectional view of the total absorption calorimeter.

cross-sectional view of the total absorption calorimeter. If the method is reliable, calorimeters made in various sizes and with different materials should provide the same energy fluence for measurements made in the same radiation field. Graphite and aluminium calorimeters were prepared. Drawing of the calorimeters are shown in Fig.2. The gap between the side wall of the absorber and the inner wall of the surrounding ring was set to 0.25 mm for all cases.

The calorimeters were irradiated together with the ECD meter, and electron energy per electron, i.e., the mean energy of the electrons, was compared. Table 1 shows the results of the measurement for accelerator voltage setting of 2.0 and 2.8 MV. The results in both materials and both sizes of the absorbers agreed.

We conclude that the absorber which consist of graphite with a 40 mm diameter opening and 12 mm thickness is optimum for 1 - 3 MeV scanning electron beams from the view point of correction of backscattering, radiation yield and resolution of measuring position.

Table 2 shows the result of calibration of CTA film dosimeter as an example of routine dosimeter calibration. The calibration yields the value, K = 0.0063 (kGy^{-1}) as the

K-value for CTA FTR-125 dosimeter. The ECD meter can be used as a monitor of the energy fluence when the electron energy is well known.

Table 1 Measured electron energy for 2.0 and 2.8 MV set in acceleration voltage.

calorimeter core		Evaluated electron energy	
material	size	accel. volt. set 2.0 (MV)	2.8 (MV)
Graphite	20 mmϕ - 12 mmt	1.96 MeV	2.79 MeV
	40 mmϕ - 12 mmt	1.85	2.70
	40 mmϕ - 20 mmt	1.93	2.82
Aluminium	20 mmϕ - 12 mmt	1.93	2.83
	40 mmϕ - 12 mmt	1.85	2.71
	40 mmϕ - 20 mmt	1.91	2.82

Table 2 Calibration of CTA dosimeter as an example.

E• = 2.0 MeV, I = 3 mA, v = 4 m/min x 5 passes

$$K = \frac{t \cdot \Sigma(\Delta OD_i)}{\phi}$$

ϕ (Joule/cm^2)	$\Sigma(\Delta OD_i)$	t (g/cm^2)	K (kGy)$^{-1}$
32.86	12.62	0.0164	0.0063

HIGH-RESOLUTION DEPTH-DOSE DISTRIBUTION MEASUREMENT FOR LOW-ENERGY ELECTRON BEAM IRRADIATION

High accuracy depth-dose distribution measurements of low energy (150 - 300 keV) electros are technically difficult. Traditionally, these measurements are not very important because low energy electrons are only used for surface treatment. However, it is possible that the development of a measuring method with high resolution will lead to new applications of low-energy electron beams.

Gafchromic^R dosimeters consist of a very thin, 8 μm, radiation sensitive layer on a 100 μm thick PET film. Gafchromic film has high radiation sensitivity even though the thickness of the sensitive layer is very small. The film has been shown to have excellent characteristics as a routine dosimeter. High resolution depth-dose profiles of low-energy electrons were obtained by a method that makes use of the thin radiation sensitive layer of the Gafchromic film.

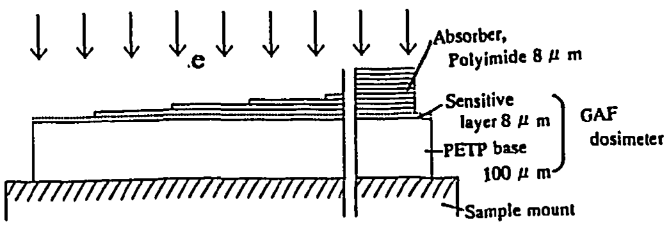

Fig.3 Experimental arrangement to measure the depth-dose distribution.

To measure the depth-dose distribution of low-energy electrons, a stepped array of absorbing material was assembled and placed upon a single layer of Gafchromic film. The step size of absorber is chosen comparable to the thickness of the sensitive layer of the dosimeter. In our experiment, we chose 8 μm Polyimide film because it has high registance to radiation exposure and it can be used repeatedly for several experiments. Figure 3 shows a drawing of the assembly and how it is oriented during exposure to the electron beam.

The assembly was irradiated by moving it through the radiation field. Figure 4 shows the results of measurements for irradiation of 200 kV and 250 kV in acceleration voltage. In the same figure, the depth-dose distributions measured using stacks of radiochromic dosimeter (FWT-60-00) are shown for comparison. It can be seen that the Gafchromic dosimeter method results in a 500 % improvement of depth resolution when compared to the conventional method.

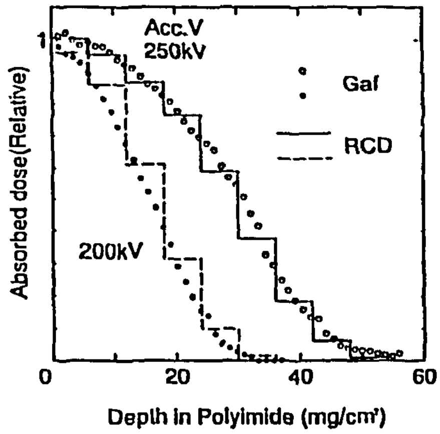

Fig.4 Depth-dose distribution in electron beam irradiation for 200 and 250 kV in acceleration voltage measured by new method.

SUMMARY

This paper reports on recent dosimeter studies at TRCRE, JAERI. It describes new methods for 1) simultaneous measurement of electron energy and calibration of routine dosimeters and 2) measurement of depth-dose distribution on low-energy electron beam irradiation with high-resolution. The energy measurement and dosimeter calibration is a simple, reliable and useful tool for standardization of irradiation parameters. The new method for generating high resolution depth-dose distribution profiles yields results that are about five times better than conventional methods. These R&D studies will cotribute to progress of radiation processing.

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